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16. Abstract

A series of conceptual designs for a manned, Earth to LEO transportation system have been developed. This study focused on non-winged, "low" L/D vehicle shapes. System and subsystem trades emphasized safety, operability, and affordability using near-term (1992) technology. The resultant conceptual design includes "lessons learned" from commercial aviation that result in a safe, routine, operationally efficient system. The primary mission for this Personnel Launch System (PLS) would be crew rotation to the SSF; other missions, including satellite servicing, orbital sortie, and space rescue were also explored.

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NOMENCLATURE

Abbrev./Acronym	Definition
ACRV	Assured Crew Return Vehicle
AFB	Air Force Base
Al	Aluminum
ALS	Advanced Launch System
APU	Auxiliary Power Unit
ARS	Advanced Recovery System
ATF	Advanced Tactical Fighter
β	ballistic coefficient
BIT	Built-in Test
BITE	Built-in Test Equipment
BTU	British Thermal Unit
CAD/CAM	Computer Aided Design/Computer Aided Manufacturing
C-C	Carbon-Carbon
C_D	drag coefficient
CEP	Circular Error Probability
c.g.	center of gravity
C_L	lift coefficient
CM	Command Module (Apollo Program)
CMC	Central Maintenance Computer
c.p.	center of pressure
D_c	critical dot product of position vector and landing site
DC	Direct Current
DDT&E	Design, Development, Test, & Evaluation
D_l	dot product of position vector and landing site
DoD	Department of Defense
DMS	Data Management System
DRM	Design Reference Mission
D_t	time interval used in orbital analysis
ECLSS	Environmental Control and Life Support System
EMU	Extravehicular Maneuvering Unit
EPS	Electrical Power System
EVA	Extravehicular Activity
F	Fahrenheit
FMEA	Failure Modes and Effects Analysis

NOMENCLATURE

Abbrev./Acronym	Definition
fps	feet per second
FSD	Full Scale Development
ft	feet
GEO	Geostationary Earth Orbit
GOX	Gaseous Oxygen
GPS	Global Positioning System
GRAM	Global Reference Atmospheric Model
GSE	Ground Support Equipment
H_2	Hydrogen
H_2O_2	Hydrogen Peroxide
hr	hour
Hz	Hertz
IMU	Inertial Measurement Unit
in	inches
klb	thousands of pounds
kts	knots
kW	kiloWatts
IOC	Initial Operating Capability
ISP	specific impulse
IVA	Intravehicular Activity
JIAWG	Joint Integration Avionics Working Group
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langely Research Center
lbf	pounds force
lbm	pounds mass
LCC	life cycle cost
LCD	Liquid Crystal Display
LCVG	Liquid Cooled Ventilated Garment
L/D	Lift-to-Drag Ratio
LEO	Low Earth Orbit
LES	Launch Escape System
LH_2	Liquid Hydrogen
LiOH	Lithium hydroxide

NOMENCLATURE

Abbrev./Acronym	**Definition**
$Li\text{-}SOCl_2$	Lithium-thionyl chloride
LLO	Low Lunar Orbit
LOX	Liquid Oxygen
LRU	Line Replaceable Unit
LV	Launch Vehicle
MAC	Military Airlift Command
MECO	Main Engine Cutoff
MEL	Minimum Equipment List
MGSS	Manned GEO Service Station
MMH	Monomethyl Hydrazine
MMU	Manned Maneuvering Unit
MPS	Main Propulsion System
MSFC	Marshall Space Flight Center
N_2	Nitrogen
NASP	National Aerospace Plane
NLP	Non-Linear Programming
NTO	Nitrogen Tetroxide
nmi	nautical miles
θ_c	crossrange angle
Ø	phase
O_2	Oxygen
OMS	Orbital Maneuvering System
O&S	Operations and Support
OTIS	Optimal Trajectories by Implicit Simulation
OTV	Orbital Transfer Vehicle
LCC	Life Cycle Cost
P	orbital period
PEAP	Personnel Emergency Air Pack
PCM	Parametric Cost Model
PLS	Personnel Launch System
POD	Point-of-Departure
P/A	propulsion/avionics
psf	pounds per square foot
q	dynamic pressure

NOMENCLATURE

Abbrev./Acronym	Definition
$\dot{q}$ or QDOT	heating rate
Q	total heating
RAAN	Right Ascension of the Ascending Node
Rc	radius of crossrange capability
RCS	Reaction Control System
RE	Radius of the Earth
RLG	Ring Laser Gyro
RP-1	Hydrocarbon Fuel (Kerosene)
RMS	Remote Manipulator System
RV	Reentry Vehicle
s or sec	second
S	reference area
SEI	Space Exploration Initiative
SIL	Software Intergration Laboratory
SOW	Statement of Work
SPF	Super Plastic Forming
SPOT	Special Performance Optimization Tool
SRB	Solid Rocket Booster
SSF	Space Station Freedom
STD	Standard
STS	Space Transportation System
TAD	Technology Availability Date
TDRSS	Tracking and Data Relay Satellite System
TM	Traffic Model
TPS	Thermal Protection System
TT&C	Telemetry, Tracking, and Control
v	volts
ΔV	velocity change (energy measurement)
VHM	Vehicle Health Monitoring
W	Weight or Watts
WBS	Work Breakdown Structure

FORWARD

This report summarizes the work performed under contract NAS9-18255, administered by the Advanced Programs Office of the NASA Johnson Space Center. The contract was performed by the Launch Systems Advanced Programs Group, Boeing Aerospace and Electronics. The contract was performed between October 1989 and November, 1990. Dr. Dana Andrews was the Boeing Program Manager; Mr. Eric Wetzel was the principal investigator.

Two subcontractors were retained to augment the Boeing staff. CAMUS, specifically Dr. Gerald Carr and Mr. William Pogue, provided an invaluable interface to and insights from the astronauts point of view. Pioneer Aerospace, a leader in high lift parachute design, provided data on recovery systems. The Pioneer team was lead by Mr. William Wailes, whose professionalism was tremendously helpful in understanding the issues associated with modern descent hardware technology.

There were a many people at Boeing who contributed to this study. Some of the key contributors were Mr. Jeff Cannon (Mass Properties and Systems Engineering), Mr. Alan Peffley (Cost Estimation), Mr. Art Scholz (Boeing Aerospace Operations, Cocoa Beach, Florida), and Dr. Phil Knowles (Propulsion and Systems Engineering). In addition, the following individuals made significant contributions to the study:

Aerodynamics-	Mr. Stan Ferguson
Aerothermal-	Mr. Richard Savage
Avionics-	Mr. Tim Mosher, Mr. Rich Flanagan, Mr. Brad Prouse, Mr. Dennis Fleischman
Configurations-	Mr. Craig Hosking, Mr. Fred Hermanspann
Cost Estimation-	Mr. Tom Wolter
ECLSS-	Mr. Paul Meyer, Mr. Tom Slavin
Electrical Power-	Mr. Len McGlothlen, Mr. Chris Johnson
Guidance-	Dr. Jerre Bradt, Mr. Matt Jessick
Operations-	Mr. Jim Hagen
Propulsion-	Mr. Calvin Wilkinson
Safety-	Mr. William Lyon
Systems Analysis-	Mr. Greg Paddock
Systems Engineering-	Mr. Gary Weber
Trajectories-	Mr. Steve Paris, Mr. Ronnie Lajoie

1 INTRODUCTION

The future of space transportation is being defined through several architecture studies, including NASA JSC's Next Manned Space Transportation Study. Requirements for several new hardware elements have been defined which will support reliable, safe, and cost effective access to space. One of the identified elements is a system designed primarily to transport people to and from space. This concept, the Personnel Launch System (PLS), will provide transportation to Low Earth Orbit for personnel but will not be designed as a (significant) cargo carrier. The stringent safety requirements associated with manned systems represent a costly added "layer" of requirements on the launch system; separate, unmanned cargo launch vehicles would avoid the extra expense and would pose no additional risk to the flight crew. Experience gained from previous space endeavors as well as from commercial and military programs can be applied to the new systems to lower costs and increase reliability.

As the current Space Transportation System (STS) approaches ten years of operations, the promise of low cost, routine access to space still has not been realized. A series of launch delays and one catastrophic booster failure have shown the current system to be less than ideal in terms of safety and reliability. Operation, maintenance, and flight preparation of the STS has proven to be labor intensive and thus costly. Efforts to improve the STS are ongoing and the system will continue to be used for some time. The opportunity now exists to apply lessons learned, such as design for operability, to the new systems to lower costs while providing for safe, reliable access to space in the future.

The purpose of this study was to provide a set of PLS vehicle designs, operational concepts, and cost estimates. In addition, support to NASA was provided for evaluation of several space transportation architectures, some of which include either the current STS, a PLS, or some combination of both. The primary constraint on the PLS design was to provide a 'low' hypersonic lift-to-drag (L/D) ratio vehicle. This constraint was intended to exclude winged concepts from consideration as these 'high' L/D concepts are being examined elsewhere under similar groundrules.

1.1 Background

The earliest space transportation systems, and indeed most systems now in use, have depended on expendable launch vehicles to launch unmanned payloads and manned spacecraft. As of October, 1990, there have been 130 manned spaceflights, 94 of which have used small, "capsule" designs and, until the STS, the low flight rates resulted in the decision to expend all hardware after one use.

The Space Shuttle was developed to launch personnel and payloads together within a reusable orbiter vehicle. With the STS, a high flight rate and recovery of the expensive flight hardware was expected to dramatically reduce the cost of space transportation. Also, by the use of highly reliable and redundant subsystems, the Shuttle was to provide safe transportation for people, without the need for elaborate escape systems. The Shuttle (STS) was expected to satisfy most, if not all, of the nation's needs for launching people and cargo.

The design of a PLS, if it is to be an improvement over competing concepts, must not only consider safety but must address those areas which have resulted in the high STS costs. The operating concept, a major cost driver, must be involved in design starting at the conceptual level.

1.2 Objectives

The objectives of this study were concerned with supporting NASA's assessment of the nation's future space transportation needs. Specifically, this study was intended to provide:

- Conceptual designs of a low hypersonic L/D personnel transportation element,
- Operations concepts that would approach airline-typereliability and operating costs,
- Space transportation with significant improvements in safety and crew survivability in the event of a major system malfunction, and
- Cost estimates for the selected PLS conceptual design that are consistent in format with other NASA costing efforts.

1.3 Groundrules and Assumptions

The given groundrules and assumptions used as the basis for conceptual design activities were as follows:

a) The primary design goals for the PLS must include
- safe transportation for people to and from Earth orbit
- high reliability and high performance margins
- lower life cycle cost than current launch systems
- efficient operation and maintenance
- routine access to space

b) Technology availability date (TAD) of 1992, with operations continuing to the year 2020 and possibly longer

c) The primary launch site will be Kennedy Space Center but other launch sites should be considered

d) The PLS has no explicit requirement to carry payloads

e) The number of crew and passengers will be determined by mission requirements and will be the subject of engineering trade studies

f) The PLS must provide for crew escape in the event of a launch vehicle failure

g) The system must not subject the passengers to detrimental acceleration loads during ascent or descent

h) The vehicle must have a low hypersonic L/D ratio. The intent of this ground rule is to eliminate winged vehicles from consideration.

1.4 Mission Model

The PLS mission model as provided by NASA was initially based on the manned space flight requirements derived from the Civil Needs Data Base. Since that time, further effort on the Space Exploration Initiative (in particular the 90-day study of late 1989) as well as further refinement of the Space Station Freedom schedule led us to undertake a mission model analysis (see Section 4) to explore sensitivities to a changing flight manifest.

A set of five reference missions was provided at the beginning of the contract to explore the range of PLS uses. DRM 1 is the primary mission for crew rotation at the Space Station Freedom (SSF). This would include routine SSF crew changeout as well as crew delivery to the SSF for SEI missions to the moon or Mars. DRM 2 is a SSF standby vehicle much like the Assured Crew Return Vehicle (ACRV). Since the ACRV study is well underway and producing similar conceptual design data, DRM 2 has been effectively ignored in this study. DRM 3 is an orbital rescue mission launched to the SSF or other manned spacecraft to effect a space rescue. DRM 4 is a scientific orbital sortie mission for the purpose of research in low Earth orbit. Finally, DRM 5 is a satellite servicing mission where the PLS would rendezvous with orbiting hardware that needs repair or servicing.

1.5 Study Tasks

The Conceptual Designs Study for a Personnel Launch System contract consisted of four main tasks:

Task 1: Review of Past Work

Task 2: System Definition

Task 3: Cost Estimation

Task 4: System Recommendation.

The tasks were time phased as shown in Figure 1.5-1.

Task 1 was divided into three subtasks. Task 1a was a review of the references provided by JSC (see References 1 through 4). Task 1b was a literature search

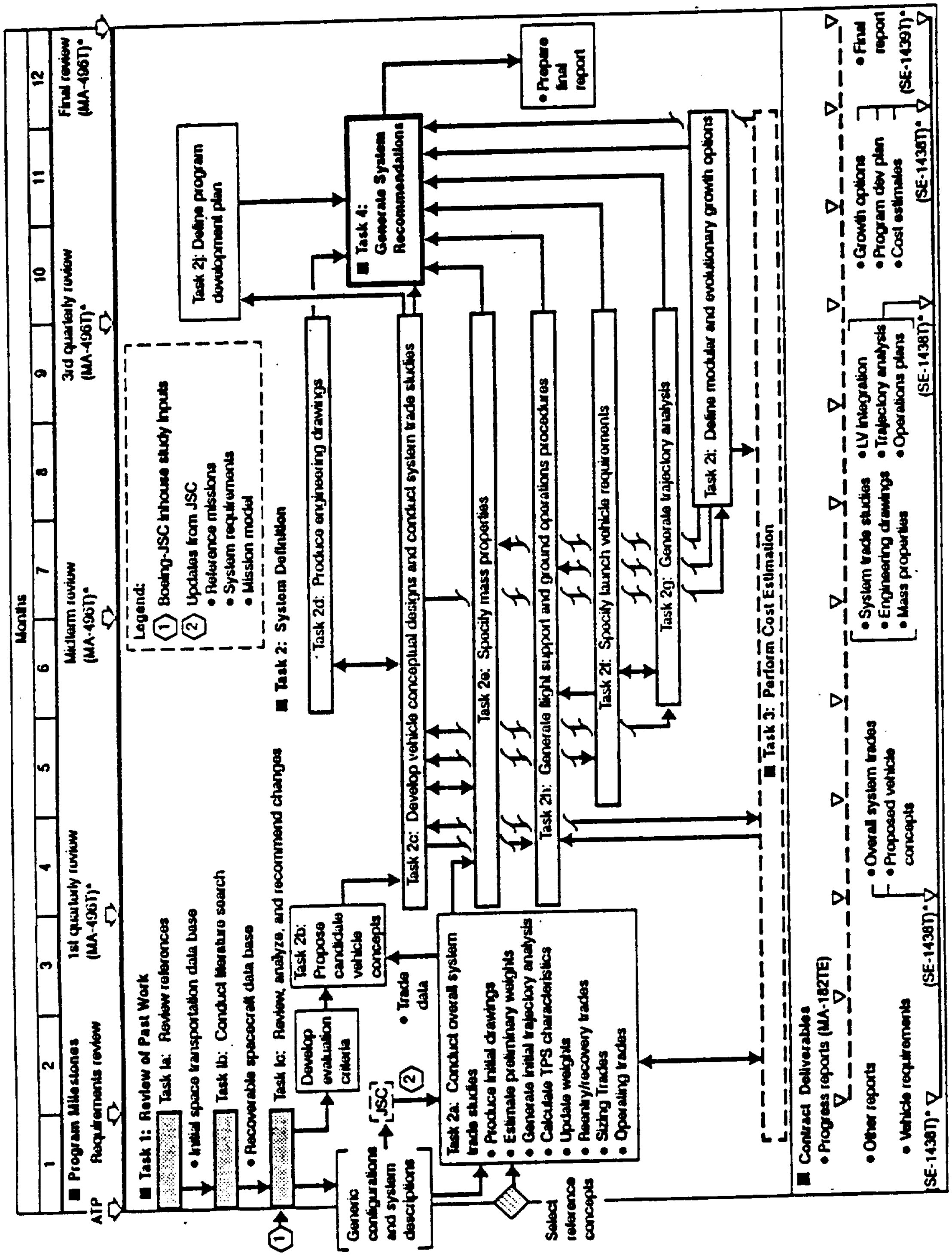

Figure 1.5-1 PLS Contract Task Flow

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conducted to assemble pertinent manned system data (including ACRV) and recoverable ballistic and lifting body vehicle data to apply to a PLS design. Finally, Task 1c was to review, analyze, and recommend changes to the given JSC in-house design(s) and program requirements and/or groundrules.

Task 2 comprised the bulk of the technical work in the study and was divided into ten subtasks. Task 2a consisted of a series of system trade studies, including such trades as number of personnel, crossrange capability, water vs. land, etc. In Task 2b, a series of vehicles were to be proposed that satisfied the reference missions. Task 2c was the actual design of vehicle concepts and included subsystem trade studies. Task 2d involved the production of engineering drawings, and 2e is where the accompanying mass properties data was generated. Task 2f was to define launch vehicle requirements. In Task 2g, trajectory analysis was performed for ascent, entry, and abort phases while 2h generated flight support and ground operations procedural outlines. Task 2i defined modular and evolutionary growth versions of the baseline PLS. Finally, Task 2j was to define a program development plan for all phases of PLS development and operations in conjunction with other NASA programs.

In Task 3, cost estimation was performed both in support of trade studies and to document selected concept life cycle costs.

Using results of the cost estimates, assessments of growth potential, mission acceptability, etc defined in Tasks 2 and 3, Task 4 recommended a limited set of vehicle concepts for further development.

1.6 Report Overview

This final report is arranged in approximate order with the tasks discussed in section 1.5 and is contained in one volume. In any conceptual design exercise, there are often many trades and considerations that are under simultaneous evaluation. Each subsection, although concerned with one aspect of design, includes the relevant considerations from other areas.

2 AEROSPACE EXPERIENCE AND APPLICATIONS TO PLS DESIGN

The idea of a personnel space transportation element is not new, nor is the required technology. Men have flown in space for over 30 years and much has been learned in the areas of subsystem design, physiology, and operations. Spaceflight still remains, however, an expensive, risky endeavor and cannot be considered routine. Suggestions have been made that there are lessons to be learned from other aerospace transportation systems, such as commercial airlines and military aircraft, which can be applied to space systems. While there are differences between exo- and endoatmospheric flight, there are many similarities, and commercial and military systems are affordable and do operate safely and dependably through a range of environmental extremes.

A full description of these lessons learned could fill volumes (the References list a few excellent sources of information). This section provides an overview of some of the key findings.

2.1 Manned Spacecraft

The cumulative flights of man's spaceflight experience represents an on-going process of learning about the capabilities and problems of man in space. As impressive as the accomplishments have been, one needs to remember that man's total flight time in space is about 23 years, less than the lifetime of one human.

The referenced documents (1 through 8) describe in detail lessons learned concerning vehicle design, physiological capability, and operational experience. The following items list some of the key findings.

Automation of ground operations - recent improvements in automated test and checkout have suggested high potential savings with the inclusion of automated systems. Treating the payload as a separate, autonomous entity is also desirable. Planning for standardization of computer connections, as well as the use of standard data formats and "paperless" procedures can significantly streamline routine operations.

Management - the introduction and utilization of more innovative and flexible management systems, from procurement through engineering to the shop, can make the ground operations more efficient.

Systems engineering - developing the hardware and software from a systems engineering viewpoint enables the appropriate emphasis to be placed on safety, operational, and life cycle cost requirements and not just on performance.

Autonomy of the flight hardware - ideally, from a ground processing standpoint, the flight vehicle would be fully autonomous with built-in test provisions, fault tolerant systems, limited dependence on ground support equipment, and no flight crew. In other words, the required interfaces external to the vehicle should be minimized.

Propulsion - a fully integrated orbital maneuvering and reaction control system would simplify ground operations. Ideally, one fuel and one propellant feeding fully throttleable engines is favored. Hypergolic fluids should be eliminated, along with on-board purges and high speed and/or high pressure turbopumps. Thrust vector control, if required, is simplified by using injection or differential throttling rather than gimbaling of the engines. On-board leak detection, perhaps with a lightweight mass spectrometer, is desirable.

Hydraulics - the space hardware processing experience has identified hydraulics as an item to eliminate, based on the traditionally lengthy and dangerous processing procedures.

Landing gear - the use of integral, aircraft type landing gear that can also support the vehicle during ground transportation and servicing relieves the system of one more piece of ground support equipment.

Ordnance - the minimization or elimination of pyrotechnic devices greatly enhances ground processing safety and scheduling efficiency. At present, facilities are typically cleared of most personnel when items such as separation devices, ignition devices, range safety charges, or solid rocket motors are handled or installed. Several options, including laser initiated ordnance and applications of memory metals, have been identified to minimize the need for hazardous pyrotechnic devices.

Launch support - a "barren pad" launch site would feature a minimum of vehicle-to-pad hardware connections and would incorporate "fly-away" propellant disconnects.

Manned override - on-board "pilot" astronauts, have always demanded the capability to take control into their own hands in the event of an emergency. The use of modern avionics has made redundant strings a standard, increasing reliability, and decreasing needs for override capability. Additionally, there are areas of the flight regime in which a human cannot respond quickly enough to effect control in a positive way. However, the arguments for and against override capabilities in aerospace have raged for years and will need to be debated for application to PLS as well.

2.2 Commercial Airline Experience

The design and operation of commercial aircraft would at first seem to have little in common with manned spacecraft, other than the transportation of people above the Earth's surface. There are, however, many significant similarities between an "ideal" PLS and a commercial airline. The modern commercial airline demonstrates reliability, safety, and affordability. These features, often taken for granted, did not just happen, but were the result of years of development driven by market forces and public acceptance of a certain level of risk. Spacecraft such as the PLS may not yet be ready for a total adoption of airline practices, but there are many lessons that can be applied to space systems immediately to improve system performance over previous endeavors.

At the risk of oversimplification, the following generalizations are presented to stimulate thinking for PLS application.

Development - the development of an airliner begins only when the market need is present. Unrealistic projections ultimately result in business failure.

Testing - the vehicle is tested over a simulated lifetime, often to component failure, before any certification of operability can be granted. The entire performance envelope is known and guaranteed before paying flights occur. The manufacturer is accountable for performance and the operator has no need to test or even record flight data.

Procurement - multiyear orders which include training and spares are standard and allow the manufacturer to plan and provide for the most cost-effective product possible. The "kick-off" customers generally define the details of the vehicle, and subsequent customers must generally buy it "as-is" without new tests or certifications. Suppliers and subcontractors compete vigorously for the opportunity to do business; new vendors are always welcome, even if initial hardware is already flying.

Spares - sufficient funding is allocated up-front in the program to build and distribute appropriate spares. Problems have occured in the early program phase until the supply lines are worked out, but integral spares planning during the prototype development helps the program.

Certification - in the airline world, the operator (e.g. United), the manufacturer (e.g. Boeing), and the inspector/regulator (e.g. FAA) are all separate entities that have no vested interest in the workings of the others. This check and balance enhances safety and forces the most meaningful decisions to the forefront. For example, Boeing promises United XX.XX passenger seat miles per gallon of gas; United doesn't care what Boeing does to meet that requirement and can assume that the FAA has verified that Boeing's solution is safe.

Flexibility - scheduling of a flight can be performed minutes before a flight with any number of different vehicles. Operations costs are not driven by unexpected events but by changes in traffic demands.

Autonomous operations - on board navigation and control, even in an emergency, is performed independently of ground systems. Communications are initiated by the crew in an emergency. While some data is monitored and stored on board, little or no telemetry is sent to the ground.

Redundancy philosophy - airplanes have sufficient backups to enable an abort at any point in the flight. Often, sufficient redundancy exists such that most flights can occur with some minor malfunctions; in other words, the vehicle does not have to be perfect to fly its mission. In aircraft parlance, a Minimum Equipment List (MEL) is certified as flight worthy. This allows the flight to be safely and reliably performed with less than 100% of the systems in full health.

Maintenance - in addition to designing for maintainability (access, standardized GSE, and built-in test) and providing the appropriate repair manuals and service bulletins, the manufacturer's warranties include certain non-standard maintenance to be performed anywhere, anytime by the manufacturer. This maintenance program is developed in parallel with the vehicle design, not later. The personnel used by the airlines are highly trained technicians which can perform a range of functions - specialization is limited to major areas, such as propulsion, avionics, etc. instead of to more specific job skills which often requires carefully orchestrated maintenance scheduling. Integrated testing eliminates the duplication inherent in serial testing. Built-in test requires sufficient allocation for sensors and appropriate location, number and type of these sensors can actually reduce the requirement for access to certain parts of the vehicle. Also, the test equipment must be able to identify faults in itself to reduce the number of false indications of flight hardware test failure. Finally, it is interesting to note that the most successful airlines tend to perform more than the minimum required maintenance; customer satisfaction has proven to have economic value.

2.3 Military Aircraft Experience

Again, it would initially appear that there is little connection with a military airplane and a spacecraft. Military aircraft are designed to operate in demanding and hostile environments, often more demanding than space. They employ new and unproven technology and are serviced by young, inexperienced personnel. Despite these handicaps, the overall system does manage to perform its mission at an acceptable cost (both in terms of dollars and human safety). There are indeed some general lessons to be learned from this experience.

Robustness - a successful design can be achieved which allows for extreme operating conditions, hostile damage, and mishandling by inexperienced personnel. Repair procedures using a combination of planned and makeshift equipment and facilities is normal; flexibility is essential in meeting operational goals.

Servicing/Maintenance - built-in servicing provisions and extensive documentation are required for use with inexperienced personnel. All procedures must be demonstrated by the manufacturers before acceptance.

Longevity - programs typically see several block "mods" during their lifetime. The basic vehicle design has many "scars and hooks" to accommodate modifications and growth, often without requiring the vehicle to be returned to the manufacturer. In this way the vehicle's capability is kept current over a longer period of time (with the associated cost benefits).

Procurement - competitive bidding often includes fly-offs of prototype vehicles. While the cost to the manufacturers is significant, winners are compensated by long-term, high value contracts.

3 CONCEPT OPTIONS

As mentioned in Section 1, the intent of this study was to focus on non-winged, low hypersonic L/D shapes. Even with this restriction, there are still a multitude of possible shapes that could be used. Many of the shapes have actually been flown in the past 35 years as either manned or unmanned reentry vehicles.

In general, this low L/D class of concepts is characterized by simple shapes, usually bodies of revolution comprised of conical and spherical segments. Figure 3.0-1 shows a range of shapes, separated by their typical ballistic coefficients and by their entry attitudes. Many familiar concepts, such as the Mercury, Gemini, Soyuz, and Apollo shapes are flown with a large, blunt shield facing the flight path. This method tends to produce little normal component force (i.e. lift) but reduces the heat load at any one point. These shapes are also fairly tolerant of longitudinal variations in the center of gravity (c.g.)/center of pressure (c.p.) relationship. The other class of shapes reenter with the "pointed" end first, typically at a significant angle of attack. These vehicles, while offering definite performance advantages afforded by the higher lift, can have very high heating rates on the nose and are typically sensitive to the c.g./c.p. relationship. Obviously, by changing the angles and curvatures, the number of concepts represented by Figure 3.0-1 is infinite.

Another generalization about the shapes is that, because of their simplicity and symmetry, they are relatively easy to manufacture. The high volumetric efficiency of the shapes results is a minimization of material for a given payload. In maintaining the PLS fleet, especially in later years after production facilities are gone, the simple shapes should not result in excess replacement costs. For comparison, the shuttle orbiter has thousands of unique ceramic thermal protection tiles that must be stocked or remanufactured - either of which is an expensive proposition.

As a result of the simple surface curvatures typifying the low L/D class of designs, hypersonic analysis of vehicle performance should be more accurate, enhancing crew safety, and should require less development time. Hypersonic linearized theory matches well with actual flight results and thus the expensive use of computational fluid dynamics and hypersonic wind tunnels can be reduced.

The relationship between deceleration, or "g's", that the passengers experience on reentry and the vehicle's L/D is not necessarily a simple equation. With careful

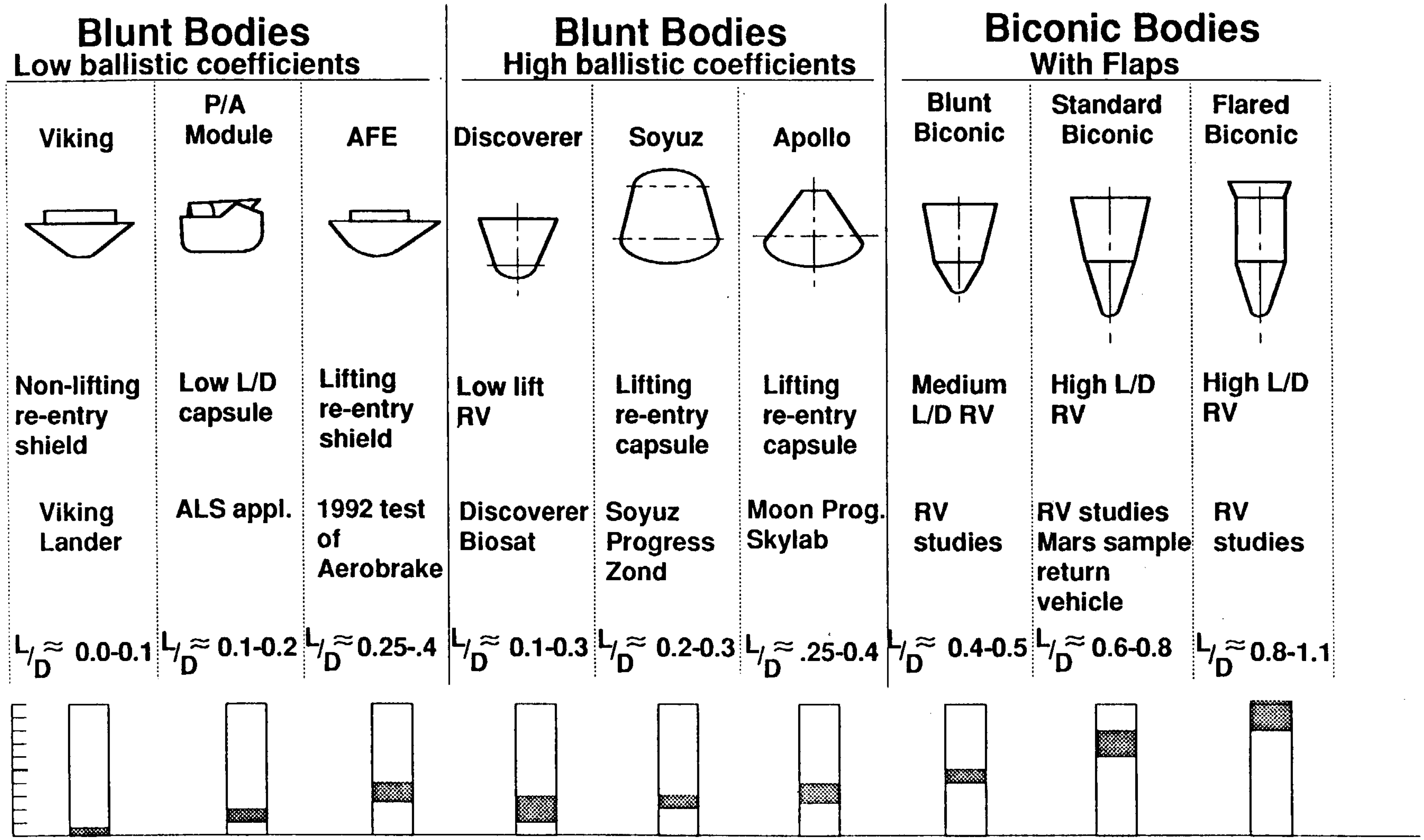

Figure 3.0-1. Candidate Low L/D Shapes

trajectory control, the range of typical g values versus L/D is shown as Figure 3.0-2. The impact of L/D on other performance parameters is discussed as part of the system trades in Section 5.1.

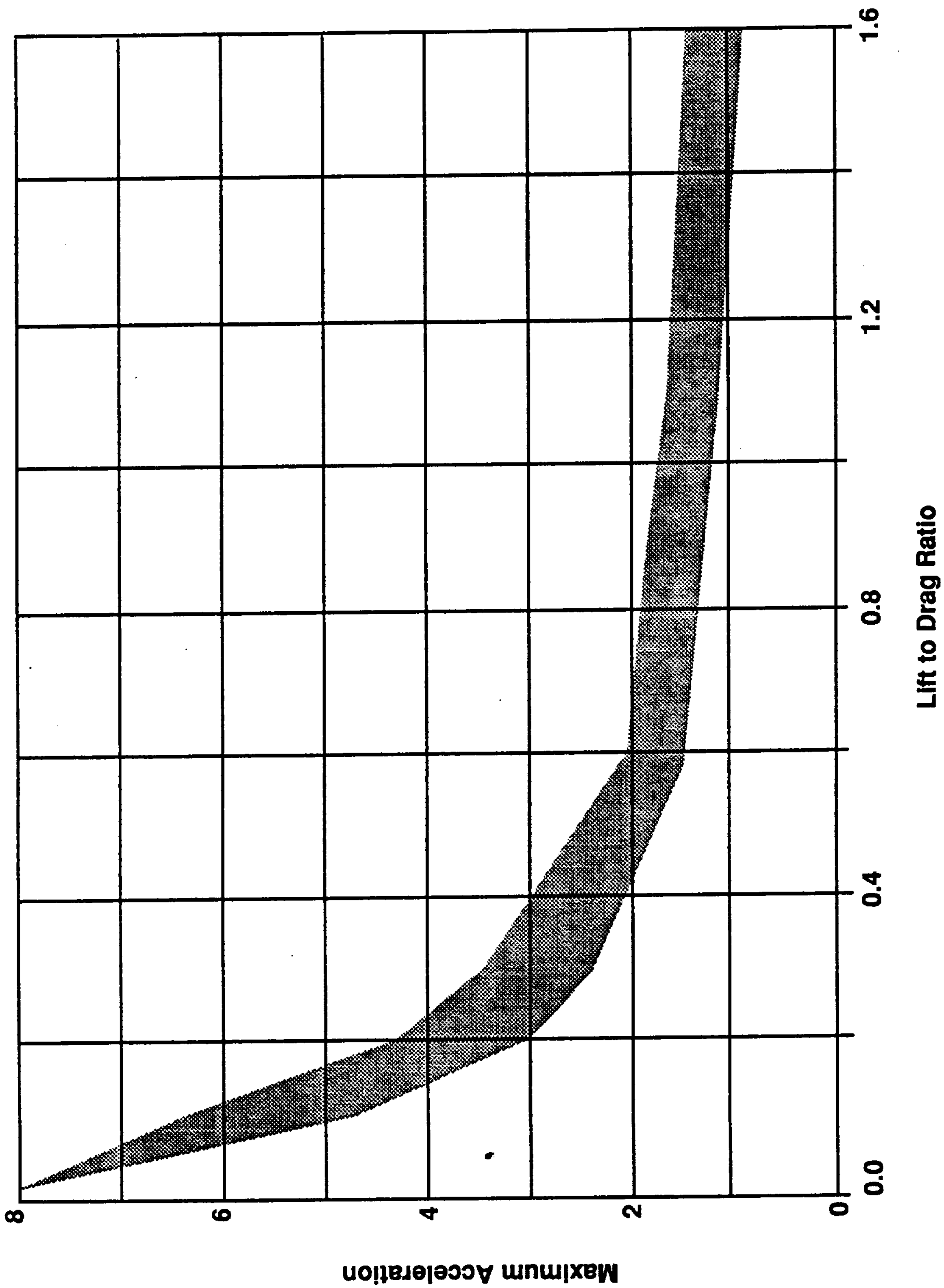

Figure 3.0-2 Maximum "g" Load versus L/D

4 MISSION MODEL ANALYSIS

One of the most significant sources of derived system requirements is the mission model. On the system sizing level, the analysis of flight rates and anticipated traffic will determine the number of personnel, the fleet size, turn-around time constraints, vehicle cycles, and mission durations (see Section 5.1). On the vehicle design level, mission timelines will determine usage of expendables, and power and life support requirements. Finally, ground processing flowtimes will determine facilities requirements and help define operations costs.

4.1 Flight Rates

The initial mission model provided in the contract included a suggested traffic model, see Table 4.1-1. Note that the traffic model is exclusive of any crew for the SSF rotation, but includes crew for the servicing missions. From an analysis of the mission model, the number of passengers per year was found, in some cases, to drive the number of missions per year above the suggested minimum number of flights per year. For the servicing missions, the number of missions had to be increased, based on the assumption of a personnel compliment of four. The rationalization for these changes was that the number of personnel delivered to orbit in order to perform the required missions was considered to be more important than the number of flights per year. The alternative would have been to keep the number of missions per year the same while reducing the number of personnel to be supported.

As was mentioned previously, the requirements for the PLS were found to be highly sensitive to the traffic model. Several alternatives were suggested to explore this sensitivity and to understand the design implications.

The first change to the given model was to incorporate a ramp-up function to full flight rate capability. Based on historical trends for other aerospace programs, it is apparent that full operational status is not a quantum step to full flight status, but is rather a gradual phase in of capability. A five year ramp-up (20% of the traffic model the first year with an additional 20% added each successive year) was used to represent this phenomenon. Note that the dates for PLS operations could slide, but the ramp function and the end date of operations would move accordingly with no effect on the conclusions.

Table 4.1-1 Initial PLS Traffic Model

Year	Station passengers	Station missions	Station pass./yr.	Servicing passengers	Servicing missions	Servicing pass./yr.	Lunar/Mars passengers	Lunar/Mars missions	Lunar/Mars pass./yr.	Total pass./yr.
1996	4	6	24	4	3	12			0	36
1997	6	5	30	4	3	12			0	42
1998	8	4	32	4	3	12			0	44
1999	8	4	32	4	3	12			0	44
2000	8	4	32	4	3	12			0	44
2001	8	4	32	4	3	12			0	44
2002	8	4	32	4	3	12			0	44
2003	8	4	32	4	3	12	4	2	8	52
2004	9	4	36	4	3	12	4	2	8	56
2005	10	4	40	4	3	12	4	2	8	60
2006	10.5	4	42	4	6	24	4	2	8	74
2007	12	4	48	4	6	24	4	2	8	80
2008	12	4	48	4	6	24	4	2	8	80
2009	12	4	48	4	6	24	8	2	16	88
2010	12	4	48	4	6	24	8	2	16	88
2011	12	4	48	4	6	24	8	2	16	88
2012	12	4	48	4	6	24	8	2	16	88
2013	12	4	48	4	6	24	8	2	16	88
2014	12	4	48	4	6	24	8	2	16	88
2015	12	4	48	4	6	24	8	2	16	88
2016	12	4	48	4	6	24	8	2	16	88
2017	12	4	48	4	6	24	8	2	16	88
2018	12	4	48	4	6	24	8	2	16	88
2019	12	4	48	4	6	24	8	2	16	88
2020	12	4	48	4	6	24	8	2	16	88
Total			1036			480			240	1756
Average			41.44			19.2			9.6	70.24

The baseline traffic model and four alternative models, listed below, were explored:

A: Assumes baseline model is too optimistic, traffic is 50% of the given model

B: Baseline model (100% of the given traffic model)

C: Assumes baseline model is pessimistic, traffic level is 150% of the given model

D: Assumes PLS is used solely for SSF rotation (DRM 1) missions, 100% of SSF portion of the given model

E: Incorporates the latest available data on SSF traffic and Lunar/Mars missions (see Reference 9).

Higher traffic models can easily sway the conclusions, particularly in the SSF rotation mission when the number of passengers is based on SSF growth versions. Graphically, the traffic models are shown as Figure 4.1-1. Note the "spiky" behavior in the out years of model E which is caused by the inputs from Reference 9. Again, the starting year of operations has slid based on work performed in the program development task which indicated that a later date was more realistic.

4.2 Mission Timelines

The activities that occur over the length of the flight, as well as the length of the flight itself, directly influence design. In particular, consumables usage and the sizing for the electrical power, environmental control, and life support subsystems are determined by timeline analysis (further discussed in Section 9).

Of particular importance to the length of a given mission is the problem of ascent and rendezvous. Orbital mechanics dictate limited opportunities for a launch and rendezvous to be possible within a reasonable length of time and with a minimum energy expenditure. Sizing a system is a compromise between launch operations flexibility (large launch windows with potentially longer missions) and human capabilities (consumables, confinement). Other factors, such as sleep schedules, shift times at SSF, lighting conditions (day/night) at rendezvous, and communications coverage must ideally be considered. At the beginning of the contract, a timeline

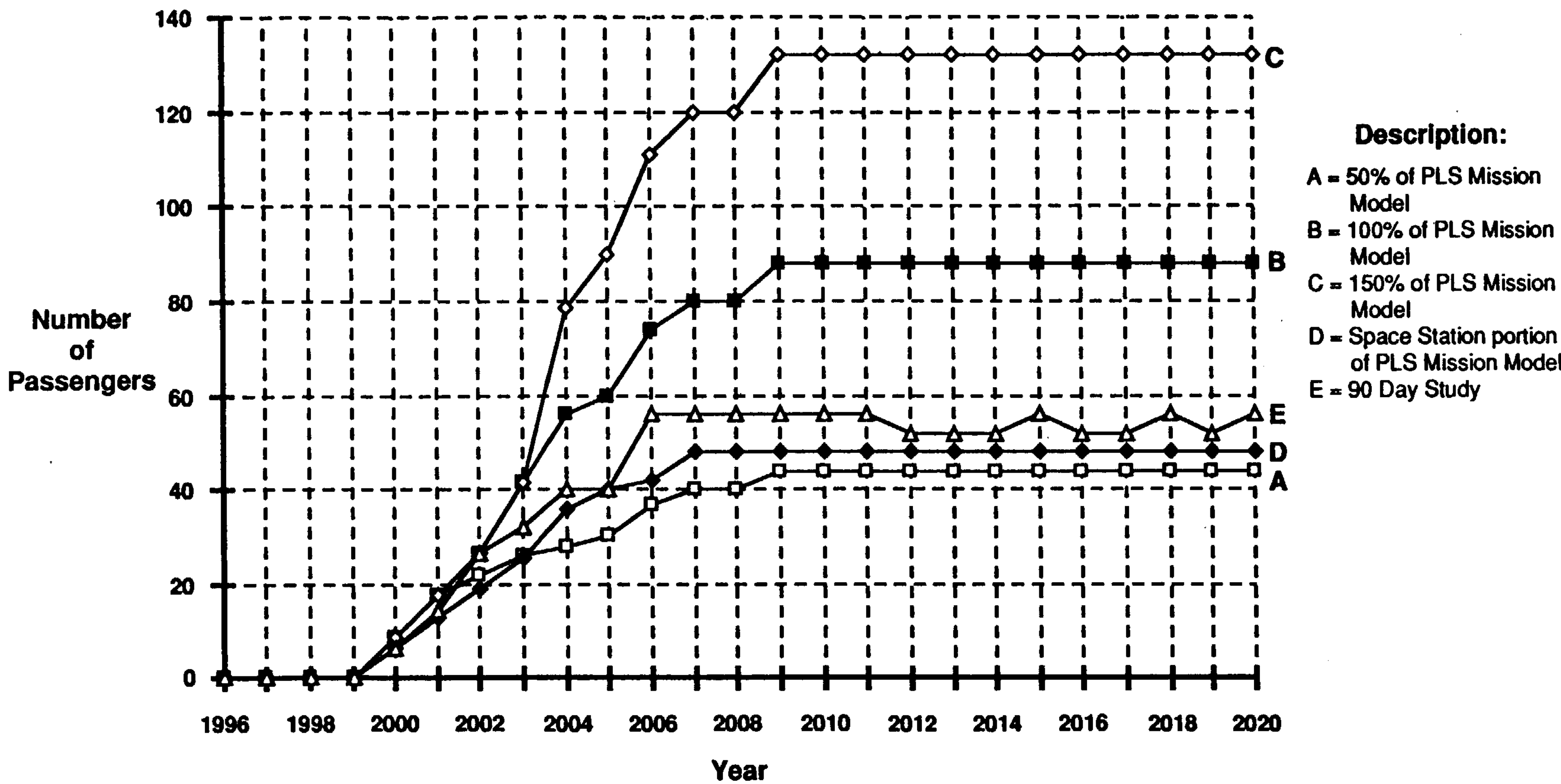

Figure 4.1-1 PLS Alternate Traffic Model

analysis performed by Rockwell STSOC (Reference 10) was provided as a baseline (see Figures 4.2-1 and 4.2-2). While this timeline would work, there are several perceived areas of deficiency, such as a large phase change maneuver and a short sleep/wake/sleep cycle which seemed undesirable.

An assessment was made of the ΔV budget and phasing time required to rendezvous with an orbiting target. The rendezvous must be completed by placing the PLS into the same orbital plane (Right Ascension of the Ascending Node (RAAN) and inclination) as the target. This can be done in two ways: the launch vehicle can perform a yaw (or dogleg) maneuver during the ascent trajectory, or; the PLS can perform a plane change after reaching orbit. (A third method, using differential nodal regression is very slow and not applicable to this mission). These approaches are shown pictorially on Figure 4.2-3.

Waiting to provide the plane change on orbit using the PLS is an expensive orbital maneuver requiring the most ΔV of the two options. The cost, in terms of ΔV, is shown in Figure 4.2-4 for a number of orbital inclinations and over a range of RAAN corrections. To the first order, 7.5° of ΔRAAN shift is needed for each hour of launch window. (The correction can be made in either direction which accounts for the 15° per hour earth rotation rate). As can be seen in the figure, there is a wide variation across the orbital inclination and even modest launch windows of 20 minutes (2.5°) can cost from 500 to 1200 ft/s.

Using the launch vehicle to correct RAAN on ascent is the standard way of achieving in-plane alignment. This is the technique used by the STS orbiter to rendezvous with it's targets. This technique does reduce the payload below that available for the maximum direct ascent trajectory, which could be a significant factor for some launch vehicles (such as a Titan). Figure 4.2-5 is an example of the reduction in performance capability associated with an off nominal launch time. The actual value is a function of the launch vehicle characteristics, orbital inclination, and launch range limitations. While this limitation must be considered, it is still more efficient to perform the alignment during the ascent trajectory than after reaching orbit.

After achieving orbit the in-plane separation angle can be reduced by waiting in a phasing orbit until such time as the final transfer will result in the desired angle between the target and the PLS. The in-plane separation angle varies through the launch window. The RAAN alignment controls the launch time, so the in-plane

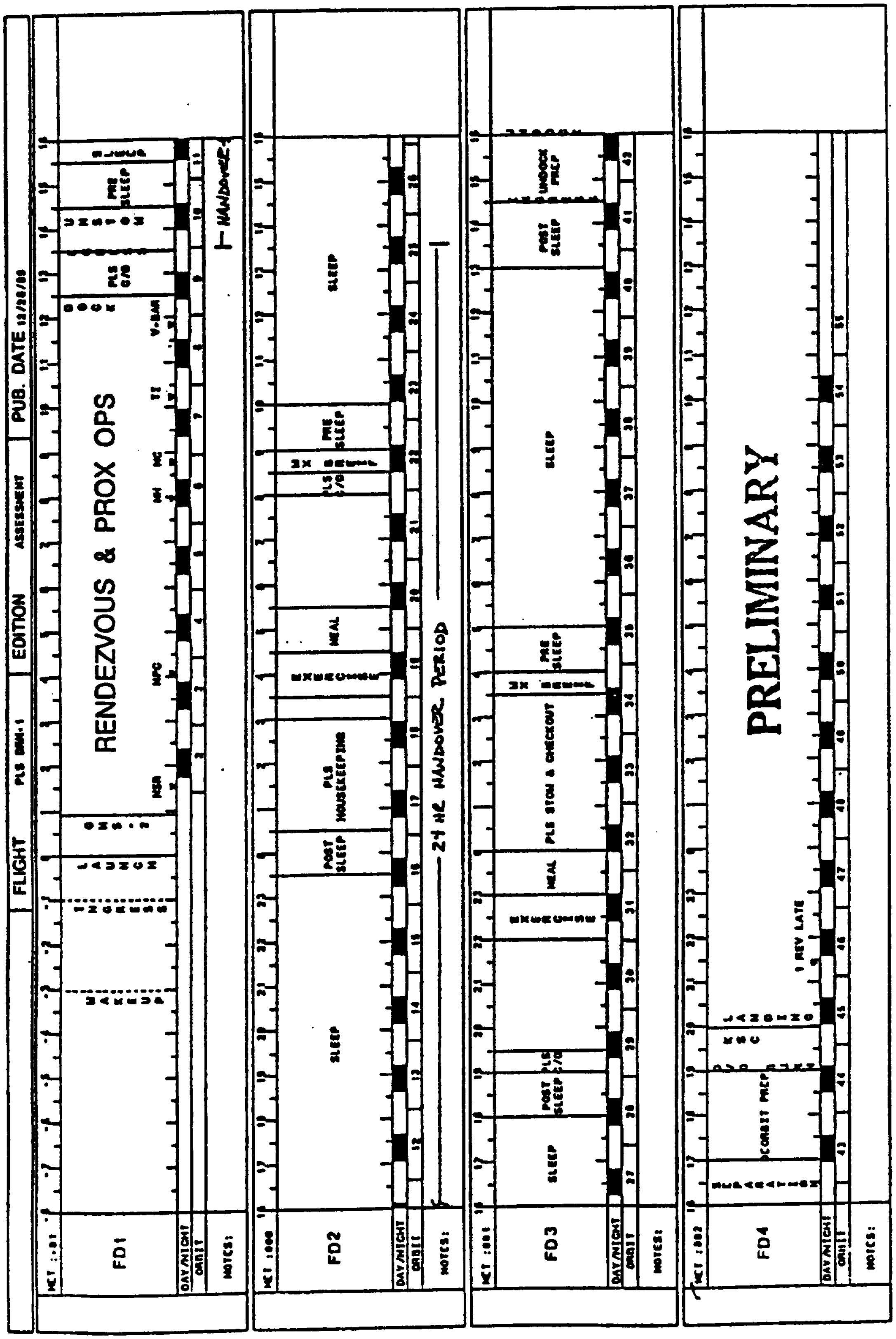

Figure 4.2-1 Baseline Mission Timeline – 72 Hours

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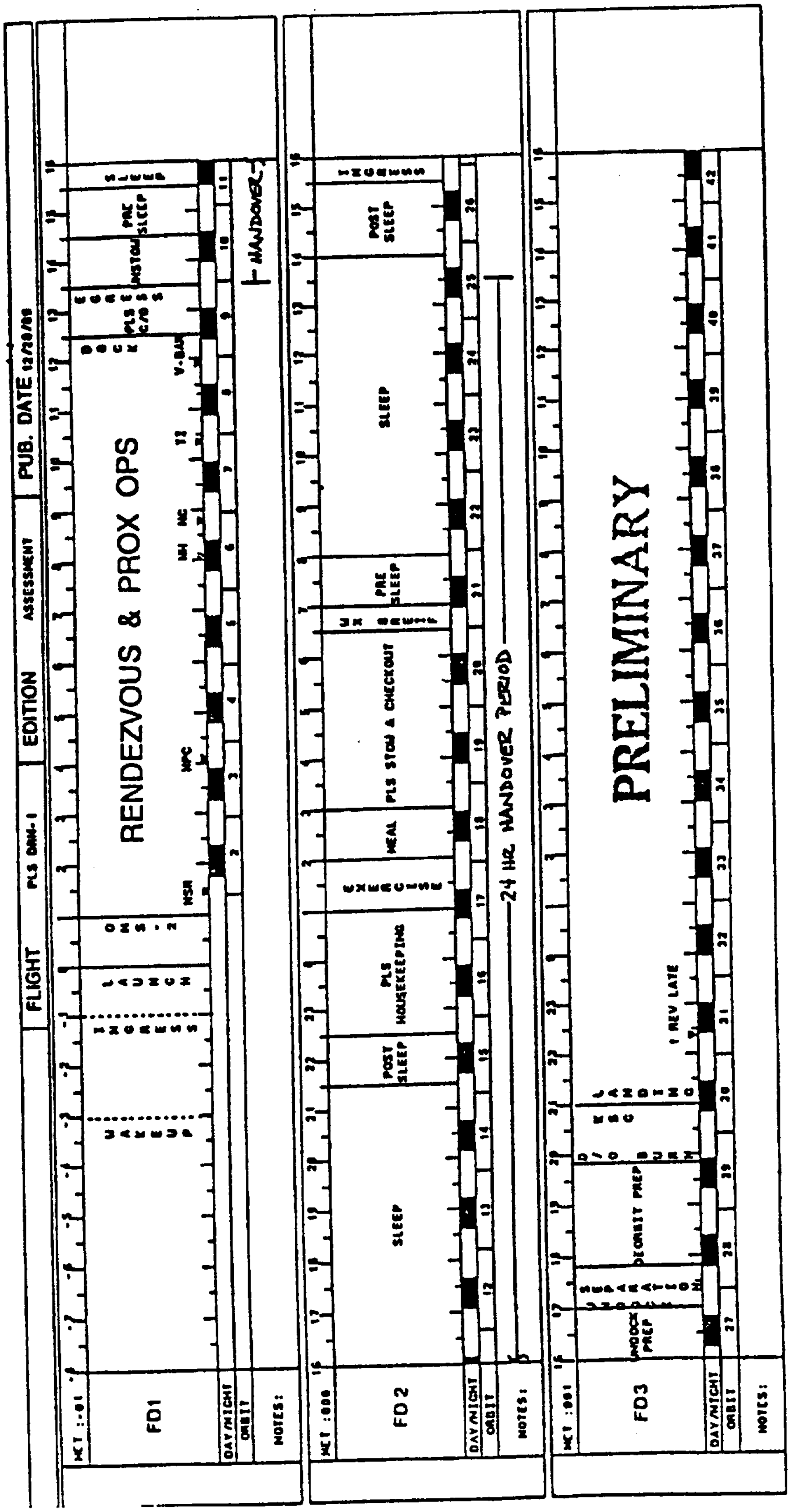

Figure 4.2-2 Baseline Mission Timeline – 48 Hours

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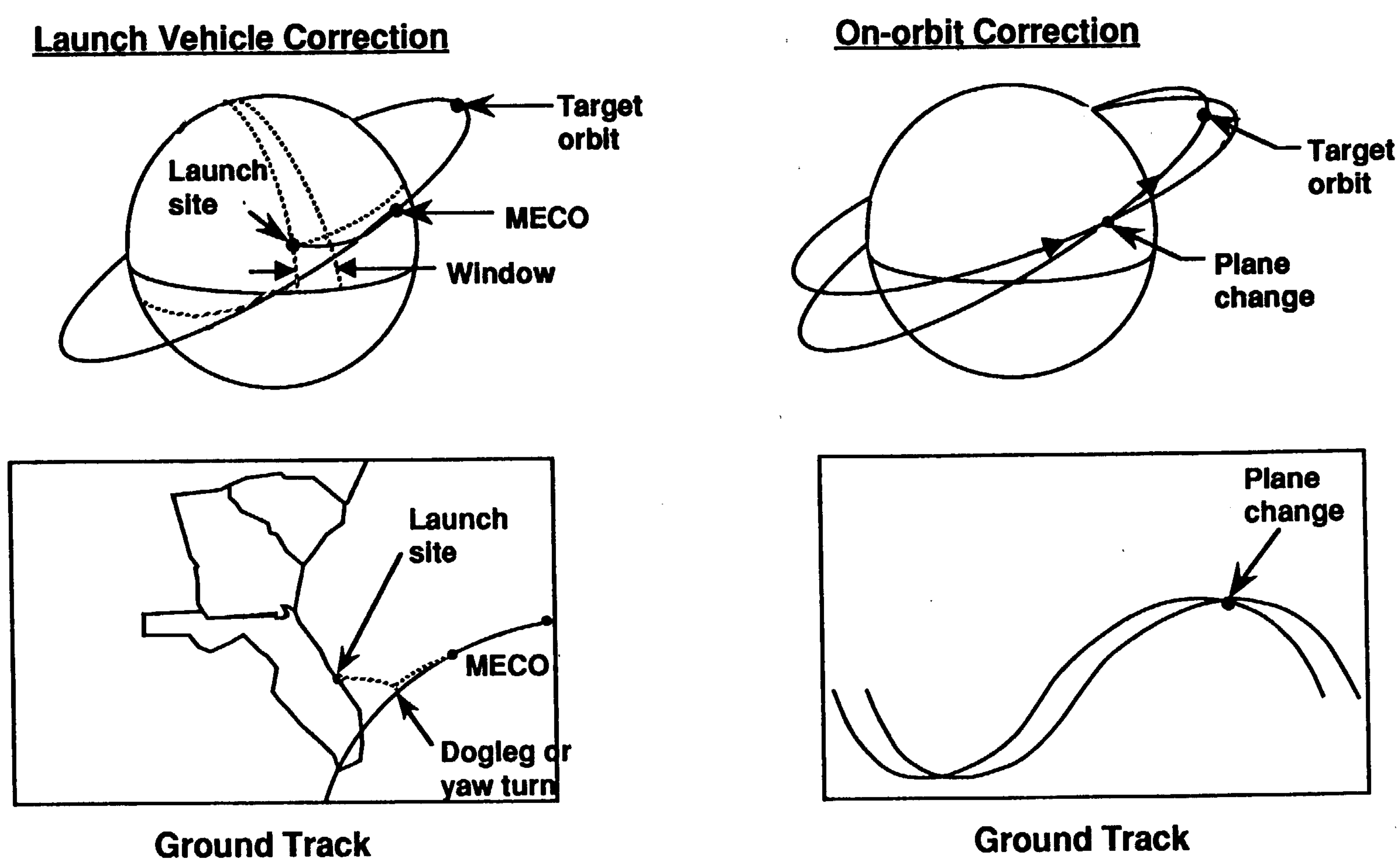


Figure 4.2-3 Methods of Rendezvous

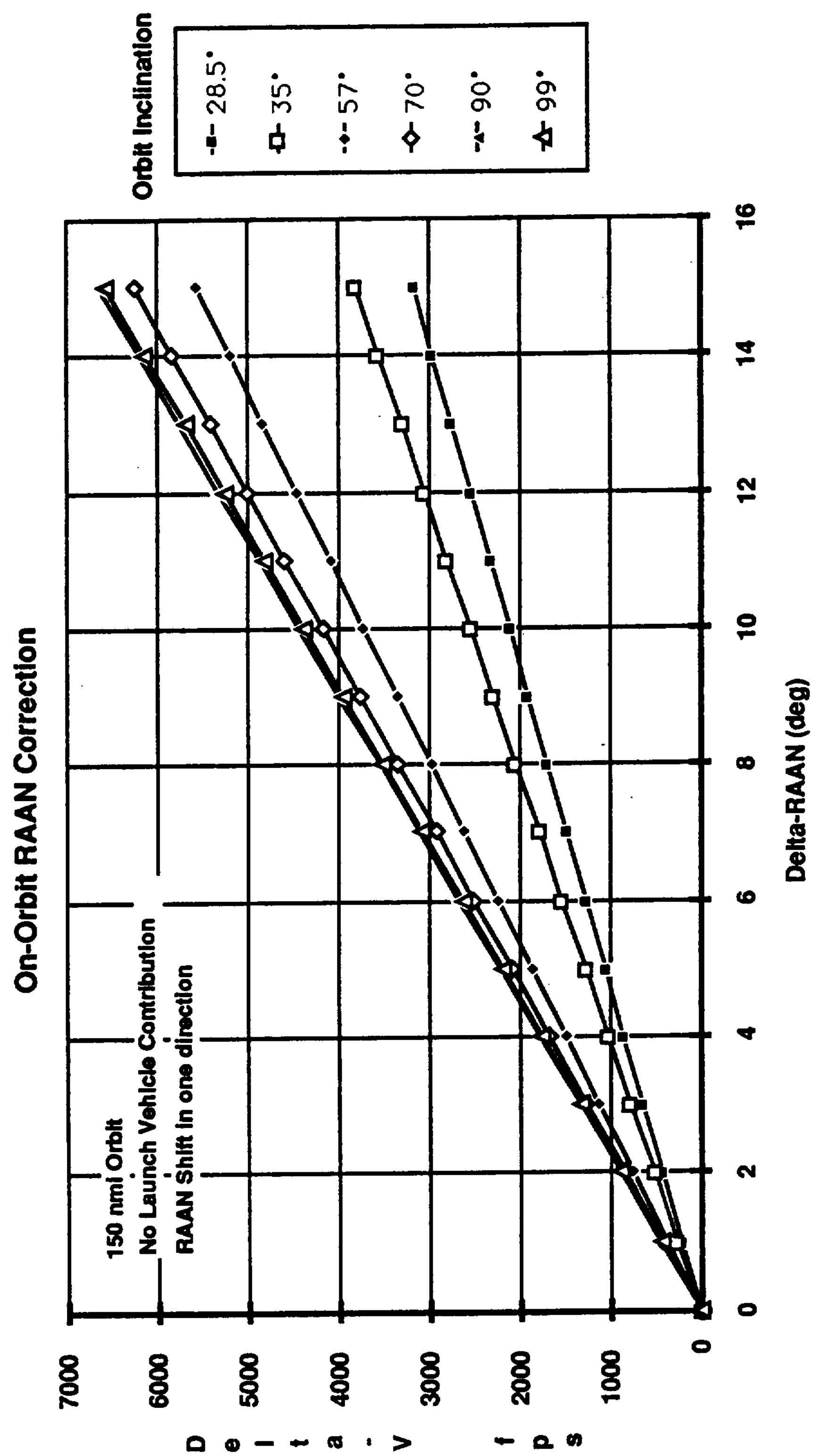


Figure 4.2-4 Launch Window ΔV Requirement

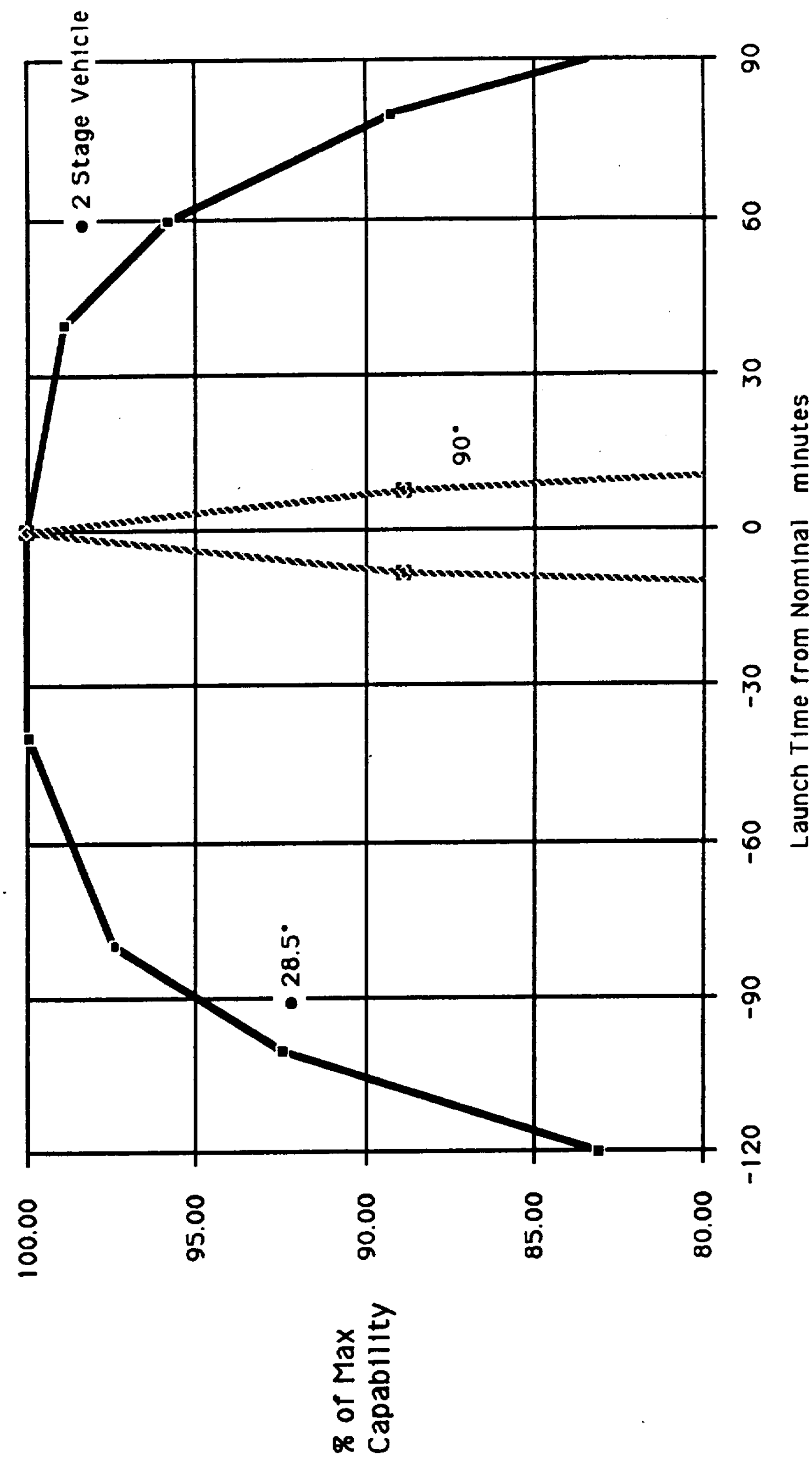


Figure 4.2-5 Launch Window Impact on Launch Vehicle Capability

separation angle cannot be controlled except by launching only during times when the angle is desirable. Three possible scenarios for the PLS to achieve the same orbital plane as the target are shown in Figures 4.2-6 through 4.2-8. Figure 4.2-6 shows a circular phasing orbit that is below the target. This is a faster orbit and so the PLS catches up to the target from below. A two burn transfer is required from the PLS to make the final maneuver. Figure 4.2-7 shows an elliptical phasing orbit whose apogee intersects the target orbit. The closing rate is not as rapid as in the technique used in Figure 4.2-6, but only a single burn has to be performed to accomplish the final rendezvous. Figure 4.2-8 shows a circular orbit higher than the target orbit, with the PLS slower than the target. Here, the PLS closes in the opposite direction from when the lower circular orbit is used (i.e. the target catches up with the PLS instead of the PLS catching up with the target). This technique can be used to reduce the total time to achieve rendezvous, but it increases the ΔV required from the PLS.

The closing rate and the velocity requirements for the circular phasing orbits, above and below, are shown in Figures 4.2-9 and 4.2-10. Data for two specific target altitudes, representative of the range expected for the Space Station, are shown in Figures 4.2-11 and 4.2-12. These show the amount of time and associated PLS vehicle ΔV required for rendezvous based on the in-plane separation angle occurring at launch vehicle MECO and on the use of the elliptical phasing orbit technique. The elliptical phasing orbit is achieved by placing the PLS into an orbit having the target orbit apogee altitude as shown in Figure 4.2-7. Consequently a higher payload capability from the launch vehicle is required than for placing the PLS in the lower circular phasing orbit.

The conclusion to be drawn from this preliminary data is that the shortest phasing times for any arbitrary separation angle occur if certain portions of the launch window use a chase from below phasing orbit and the other part of the window "chases" from above. It may be necessary to conduct operations in this way for instances of the PLS operating in a "critical" mode where rendezvous with the target must be accomplished in the shortest possible time. In other instances certain separation angles can be excluded and the window can close for a period of time or the launch be recycled to another day. If the target orbit inclination is greater than the launch site inclination, providing two launch opportunities in a day, the launch can be recycled to the second opportunity of that day.

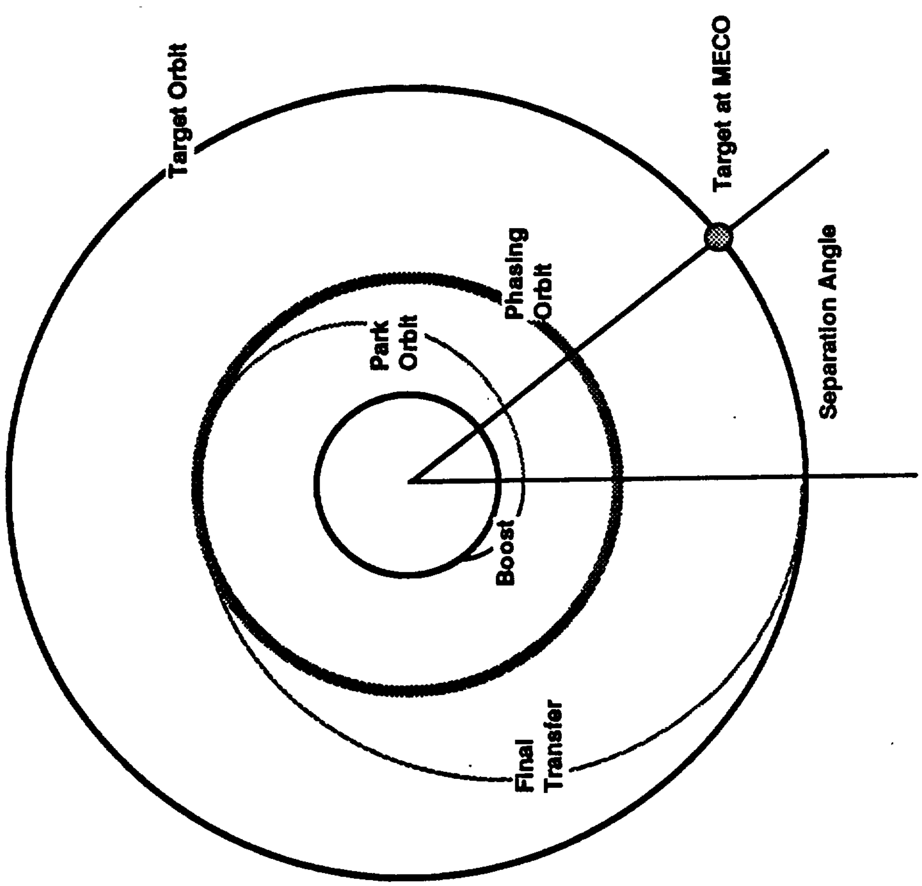


Figure 4.2-6 Chase From Below Rendezvous

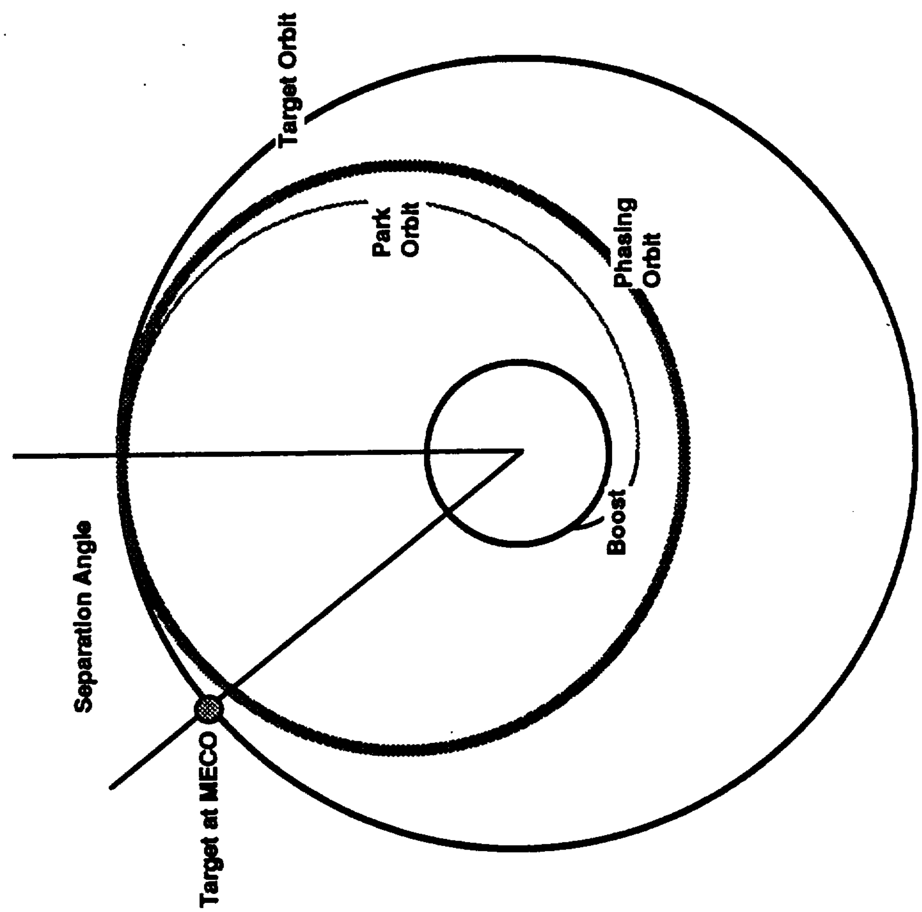


Figure 4.2-7 Intersecting Chase Orbit

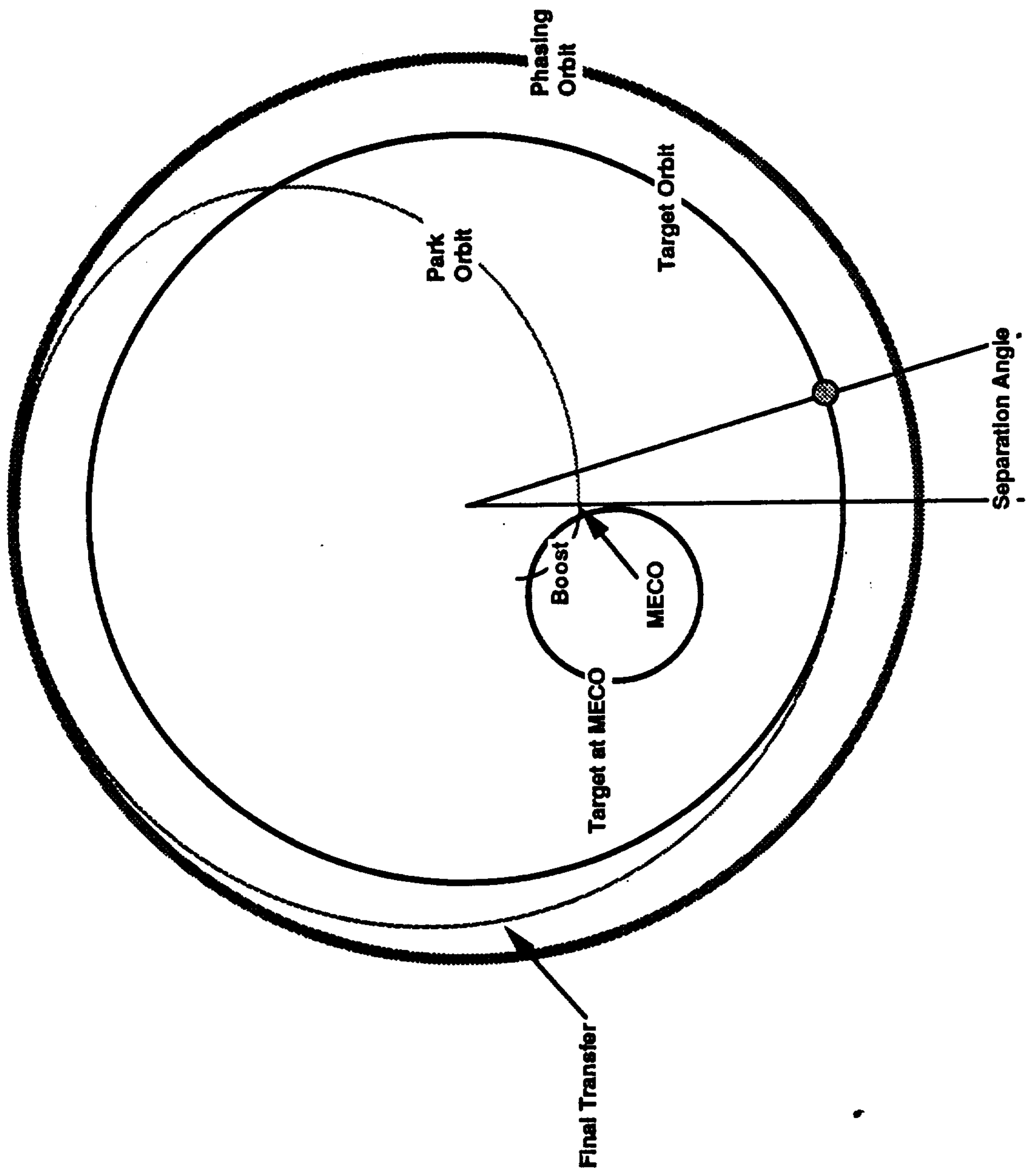


Figure 4.2-8 Chase From Above Rendezvous

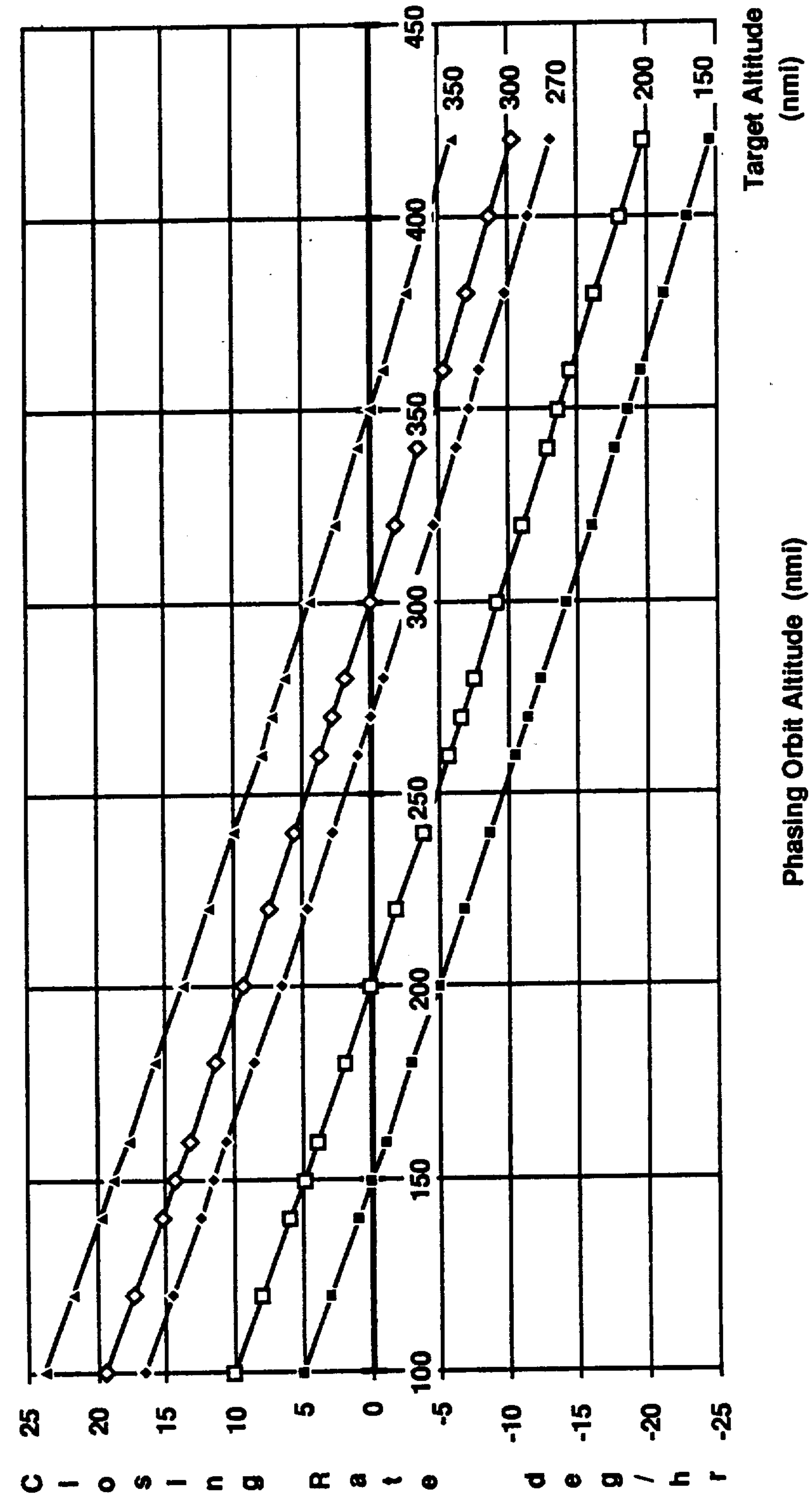


Figure 4.2-9 Parametric Closing Rate Capability

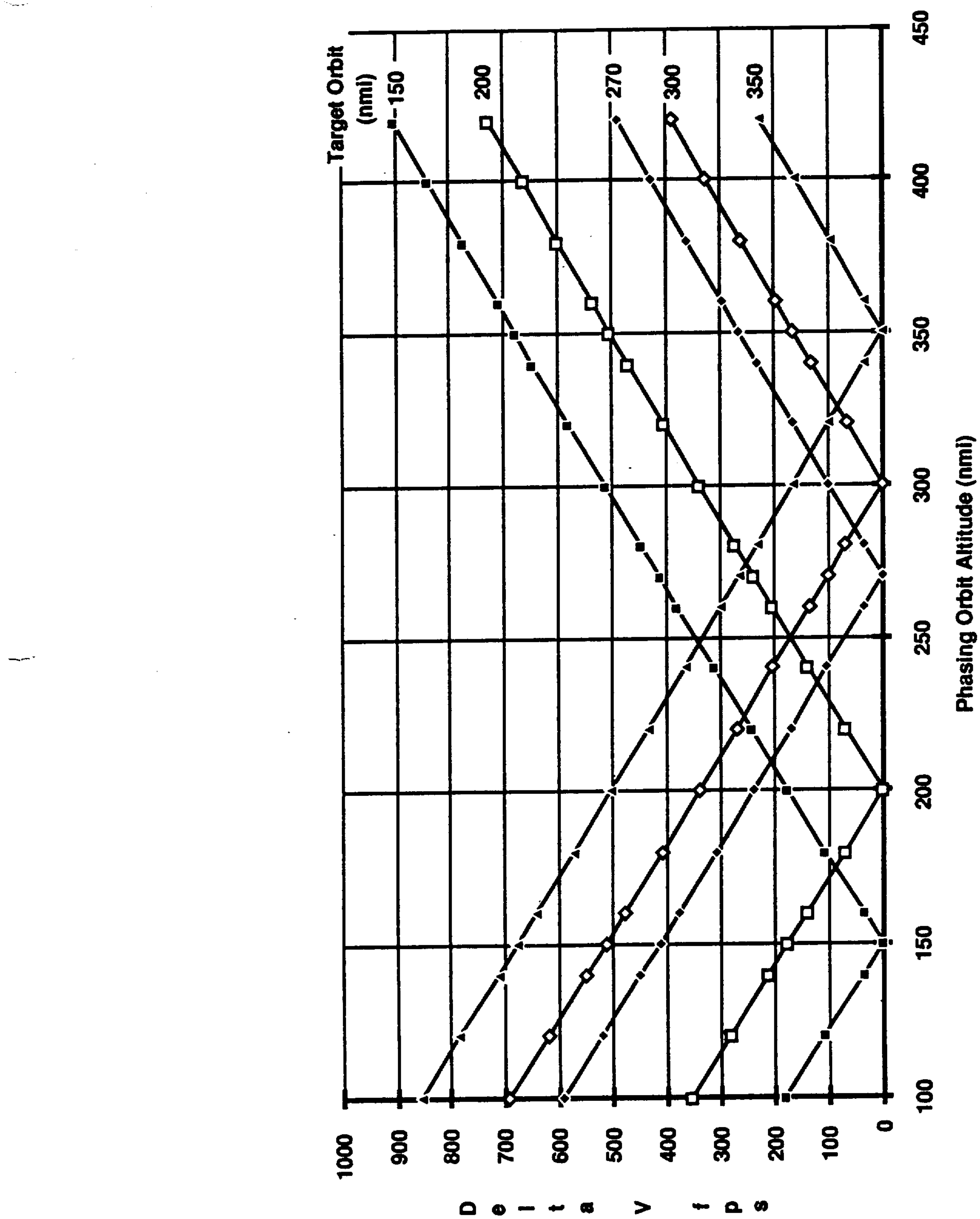


Figure 4.2-10 Parametric Phasing Velocity Requirement

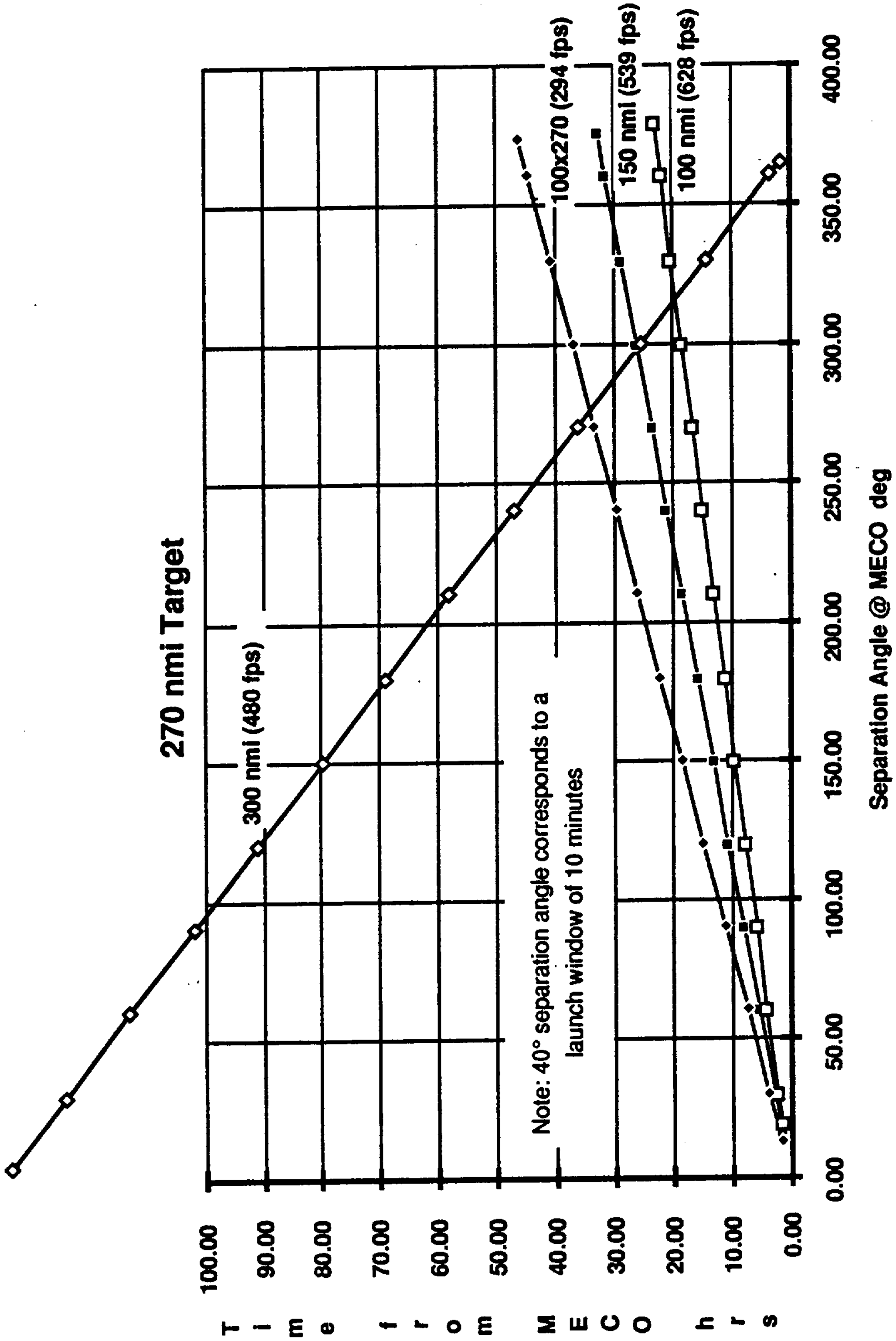


Figure 4.2-11 Rendezvous Time versus Separation Angle

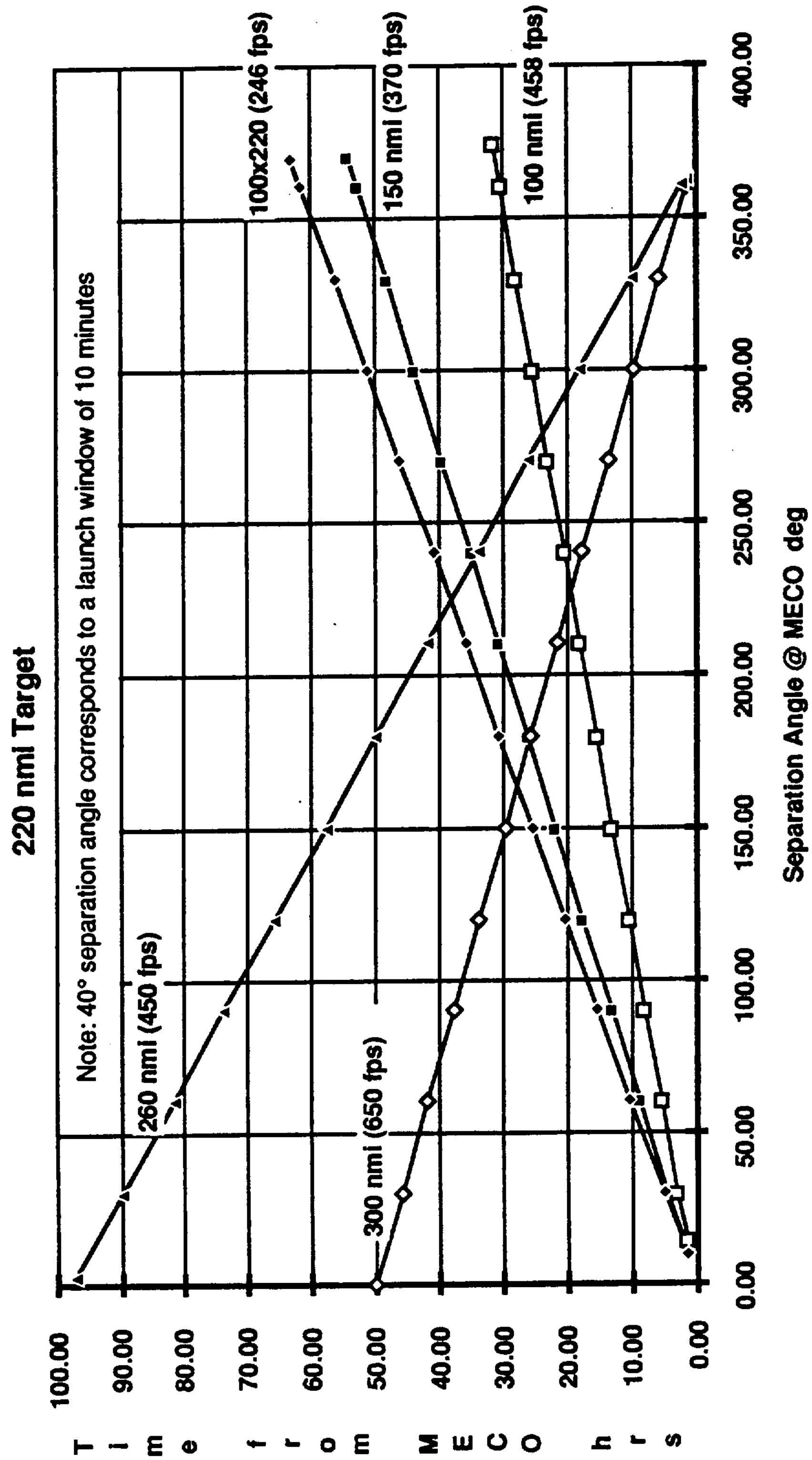


Figure 4.2-12 Rendezvous Time versus Separation Angle

These issues are closely associated with crew time limits, abort landing sites, and allowable phasing orbit time limits (crew factors and consumables). The resultant timelines which were used are presented as Figure 4.2-13. Although the timeline still shows a mission duration of 72 hours, this should be viewed as a contingency mission to determine the maximum system duration requirements. The actual mission length is a variable based on the issues discussed in this section, but would probably be in the 34 to 48 hour range for most missions.

4.3 Ground Flowtimes

The scope and length of ground processing steps has direct bearing on the operations costs of the PLS. In section 12.2, these operations are discussed in more detail.

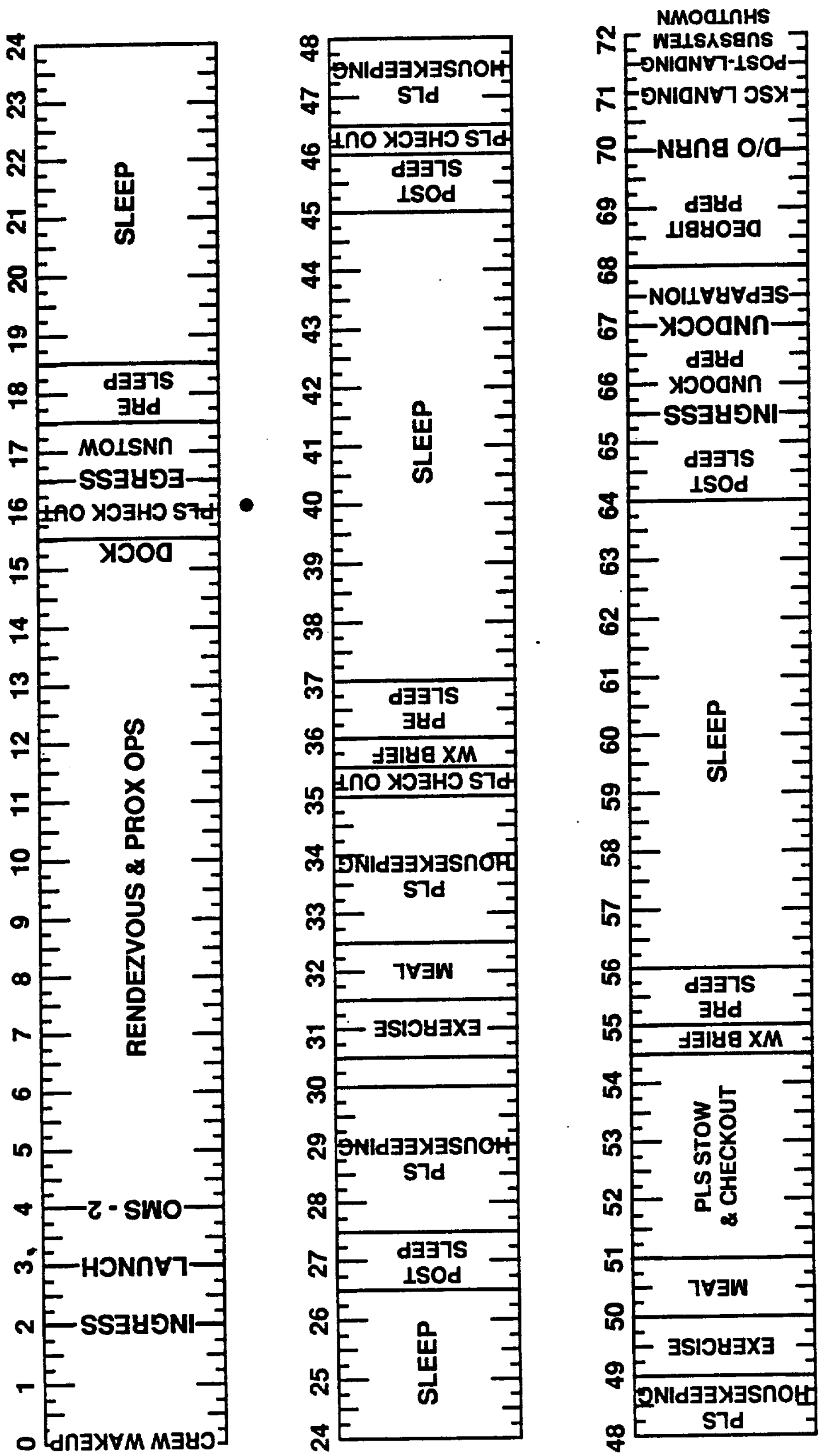


Figure 4.2-13 SSF Rotation Mission Timeline

5 SYSTEM TRADE STUDIES

The system trade studies task was performed to derive appropriate design requirements within the given operational objectives and mission scenarios. To provide a baseline and effectively evaluate the differences between system options, a point-of-departure concept was designed which incorporates proven subsystems and technology. As several trades were found to be highly sensitive to the mission model, a spreadsheet mission modelling tool was used to determine the changes that result from selecting different flight scenarios. Finally, the conclusions of the trade studies were used to update the PLS requirements for further preliminary design.

The point-of-departure (POD) concept was used to develop cost and schedule estimates against which trade alternatives could be evaluated. The selected biconic shape, shown in Figure 5.0-1, primarily uses existing technologies and subsystems. The selection of modular/expendable elements was not intended to reflect a system optimization but rather allowed for such elements to be "book-kept" separately, maximizing the traceability, and thus credibility, of the system cost estimates.

The system trade studies were grouped into three sets of trades: 1) System Sizing Trades, 2) Entry/Recovery Trades, and, 3) Utility Trades. Trade options within these groupings are frequently sensitive to one another.

5.1 System Sizing Trades

The following trades are closely interrelated and are sensitive to the mission model. Cross-referenced plots are included to aid in the understanding of these interrelationships.

To determine system characteristics and life-cycle cost (LCC) impacts of alternative system trade options, a spreadsheet mission modelling tool was written that enables the user to derive the number of flights, the fleet size, and the total number of units produced. Inputs included parametric features such as: the number of passengers; mission duration; turn-around time; flights per vehicle (also referred to as vehicle life); launch vehicle costs; and traffic models. The results are highly sensitive to the selected traffic model. The parametric inputs are also very interdependent and are plotted in various combinations to explore sensitivities to mission assumptions. Cost inputs (including DDT&E, unit cost, recurring and non-recurring costs, and launch

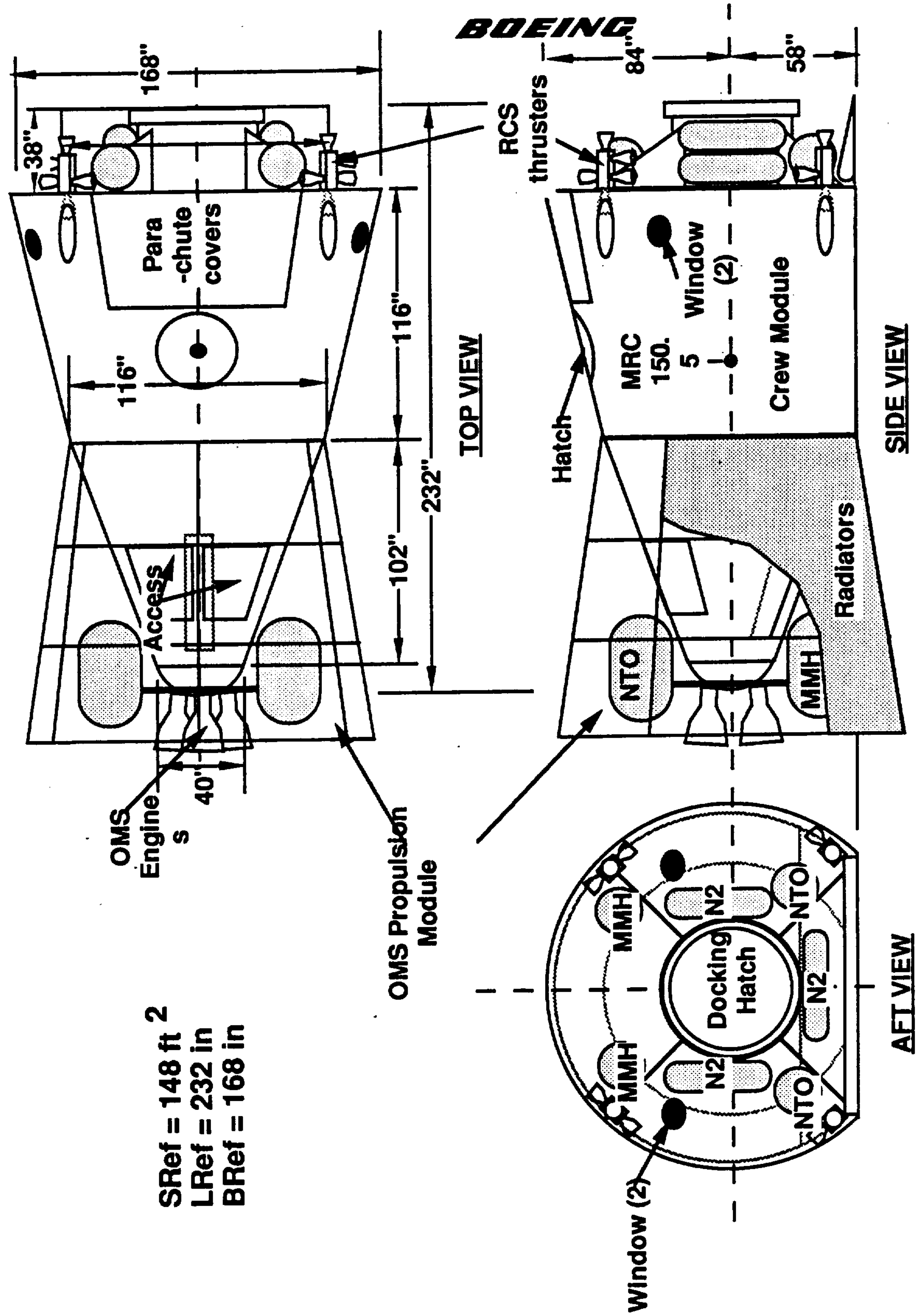


Figure 5.0-1 POD Configuration

vehicle costs) can also be added to support trade study assessments. A complete set of sensitivity plots can be found in Appendix A.

5.1.1 Number of Personnel

One of the most critical requirements from a vehicle design standpoint, is the payload volume/weight with the payload being, in this case, the passenger load. The reference mission (DRM 1) for crew rotation at the Space Station Freedom (SSF) is the driving requirement in terms of the number of passengers. Note that the mission model sets the requirement for passengers, not crew. The assumption is that the PLS will initially carry two crew members (pilot-astronaut), although the autonomy trade (see Section 9.6.4) explored the preferred long-term, operational solution, which may be 1 crew or no crew. The vehicle is sized for the combined number of crew and passengers, called personnel.

There are several aspects/issues to the size selection. It is fairly obvious that a vehicle with a larger passenger complement is physically larger and thus heavier. Figure 5.1.1-1 depicts the weight growth, related to an increasing number of passengers, for the POD concept. At some point, a larger vehicle may limit the launch vehicle selections that are available (larger boosters generally are costlier and involve longer processing flows). Figures 5.1.1-2 and 5.1.1-3 depict the impact of the personnel load on launch vehicle selection options for two representative PLS vehicles which bracket the L/D range included in this study.

Another major issue is cost. The previously described mission modelling tool was used to find any minima, in terms of life-cycle cost, which may exist over a range of personnel loads. The magnitude of the costs is highly dependent on launch vehicle costs. The location of the minima is very sensitive to the selected mission model. Figure 5.1.1-4 is based on traffic model B, whereas Figure 5.1.1-5 was based on traffic model E (see Section 4.1 for traffic model descriptions).

The third major issue involves ground operations. A larger vehicle requires larger facilities. Admittedly, at a conceptual level, these differences are hard to quantify. A more tangible constraint involves transportation. If the PLS if built, serviced, or lands anywhere away from the assembly facilities located at the launch site, the vehicle will need to be transported. To avoid the cost and complexity of moves such as the transport of the Shuttle Orbiter from Edwards AFB to KSC, we have assumed that the

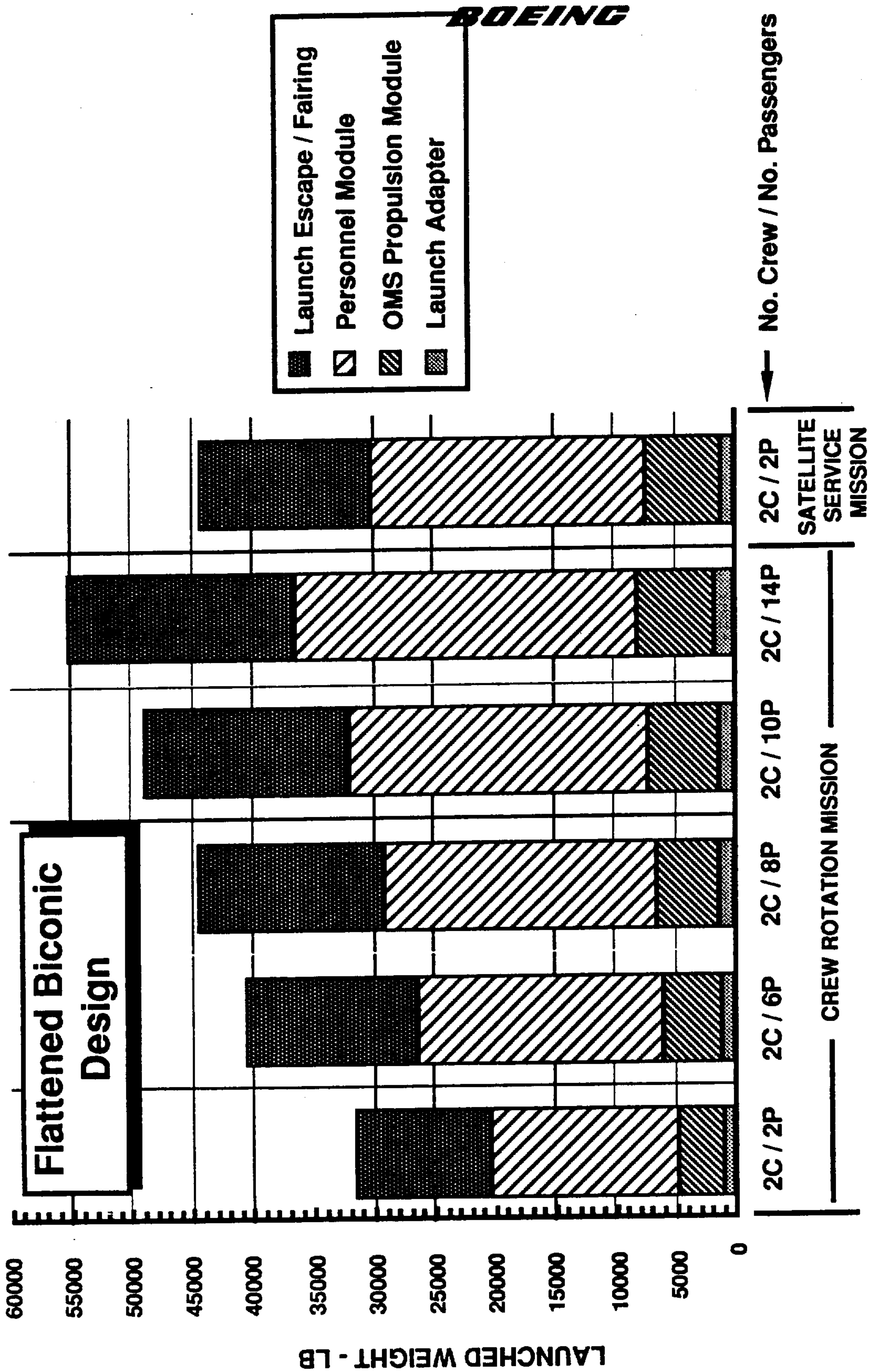
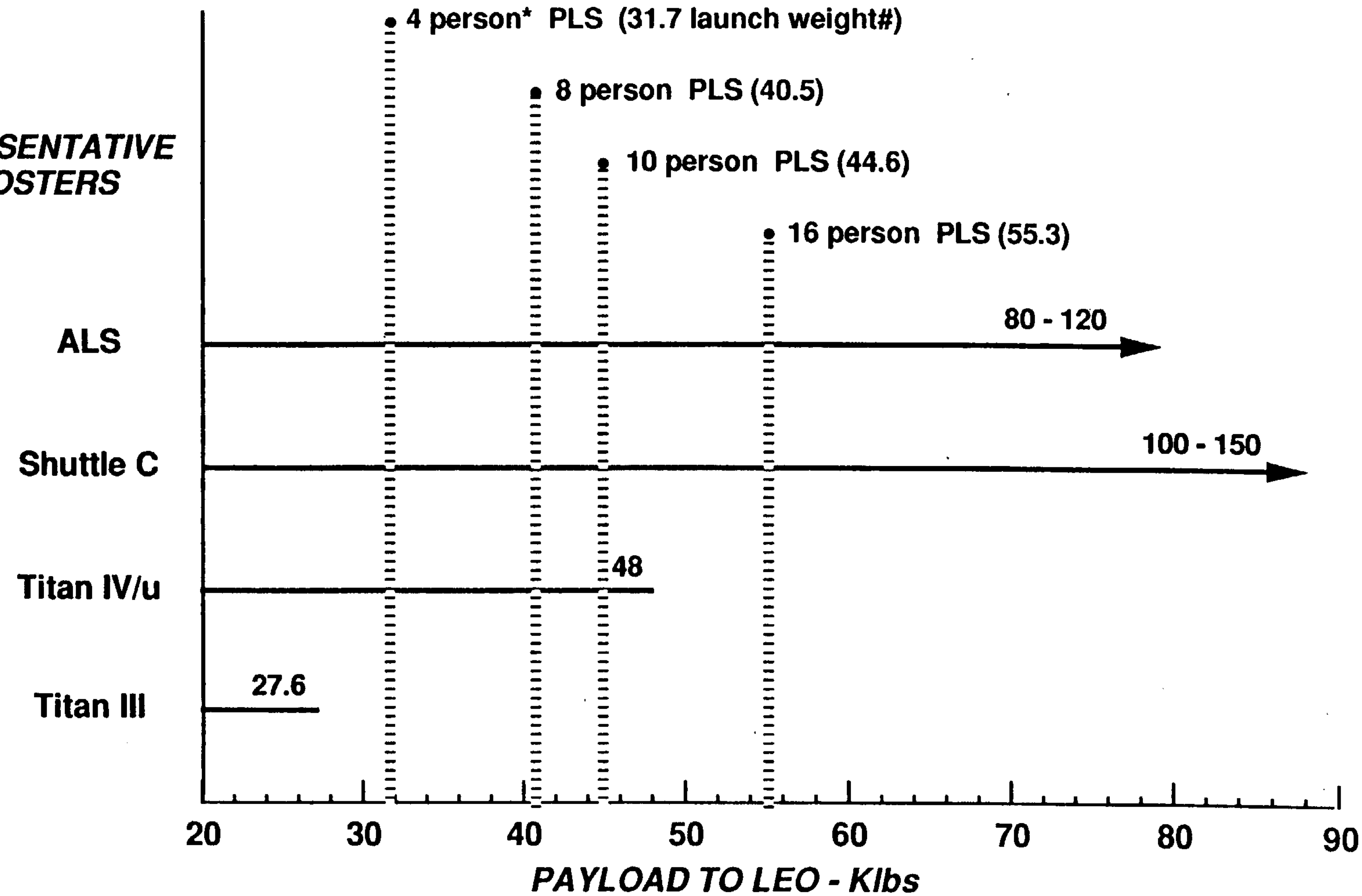
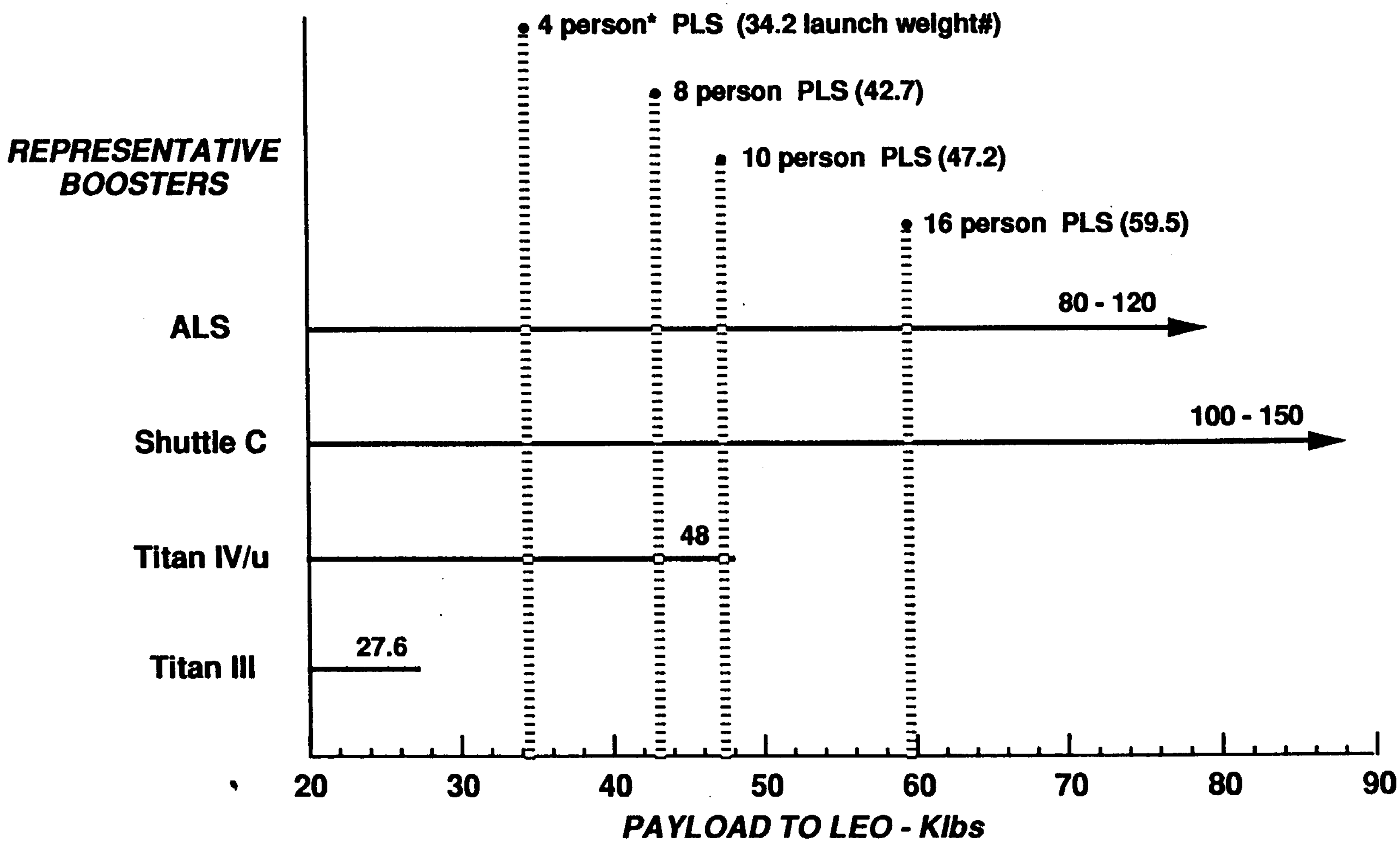


Figure 5.1.1-1 POD Weight Growth versus Number of Personnel



* Includes 2 dedicated crew
\# Based on transport mission - servicing missions = higher launch weights
MID L/D weights based on flattened biconic configuration option

Figure 5.1.1-2 Personnel Load Impact on Launch Vehicle Options - Mid L/D PLS



* Includes 2 dedicated crew
\# Based on transport mission - servicing missions = higher launch weights
LOW L/D weights based on P/A module configuration option

Figure 5.1.1-3 Personnel Load Impact on Launch Vehicle Options - Low L/D PLS

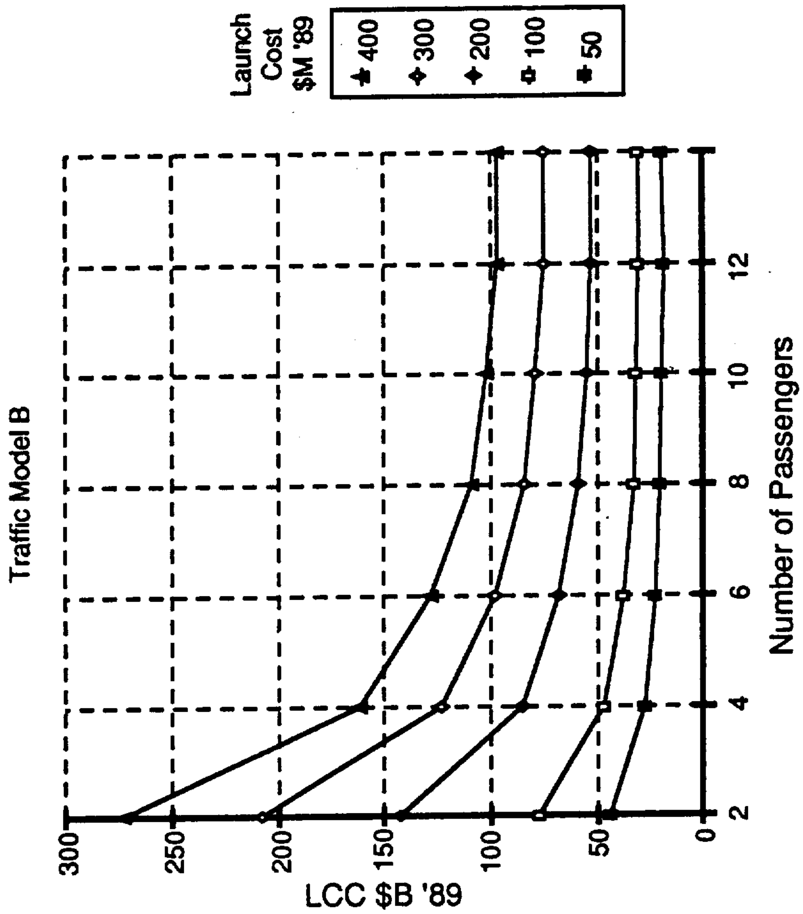


Figure 5.1.1-4 LCC versus Number of Personnel (Traffic Model B)

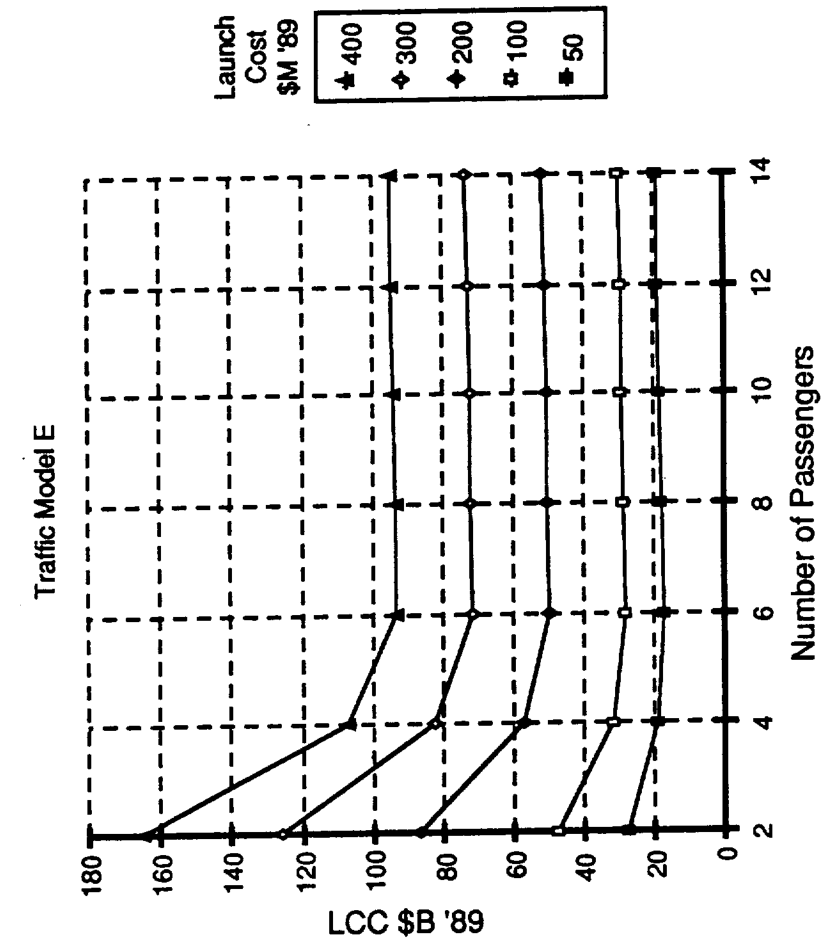


Figure 5.1.1-5 LCC versus Number of Personnel (Traffic Model E)

PLS vehicle should physically fit within a standard C-5B or C-17 for air transport. This operational assumption is consistent with standard practice for military space hardware transportation. Figure 5.1.1-6 shows how a biconic shape sized for varying personnel loads would fit within these transports. A variety of other shapes with large radius heat shields (such as an Apollo type) were found to be incompatible with personnel loads above 8 persons.

By considering all these issues, one can narrow down the range of personnel sizing. The low end of 4 to 6 persons, requires too many launches and the LCC's rise rapidly. The higher end, 12 to 16 persons, while "flat" in cost growth, severely limits launch vehicle options and ground transportation alternatives. Depending on the selected mission model, the minimum cost corresponds to a passenger load of 6 to 12. As a compromise, a passenger load of 8 was selected with 2 crew (10 personnel). This selection will:

a) permit a complete changeout of a SSF crew of 8,

b) be within the payload capability of a Titan IVu,

c) enable direct cost comparison to the LaRC lifting body, and,

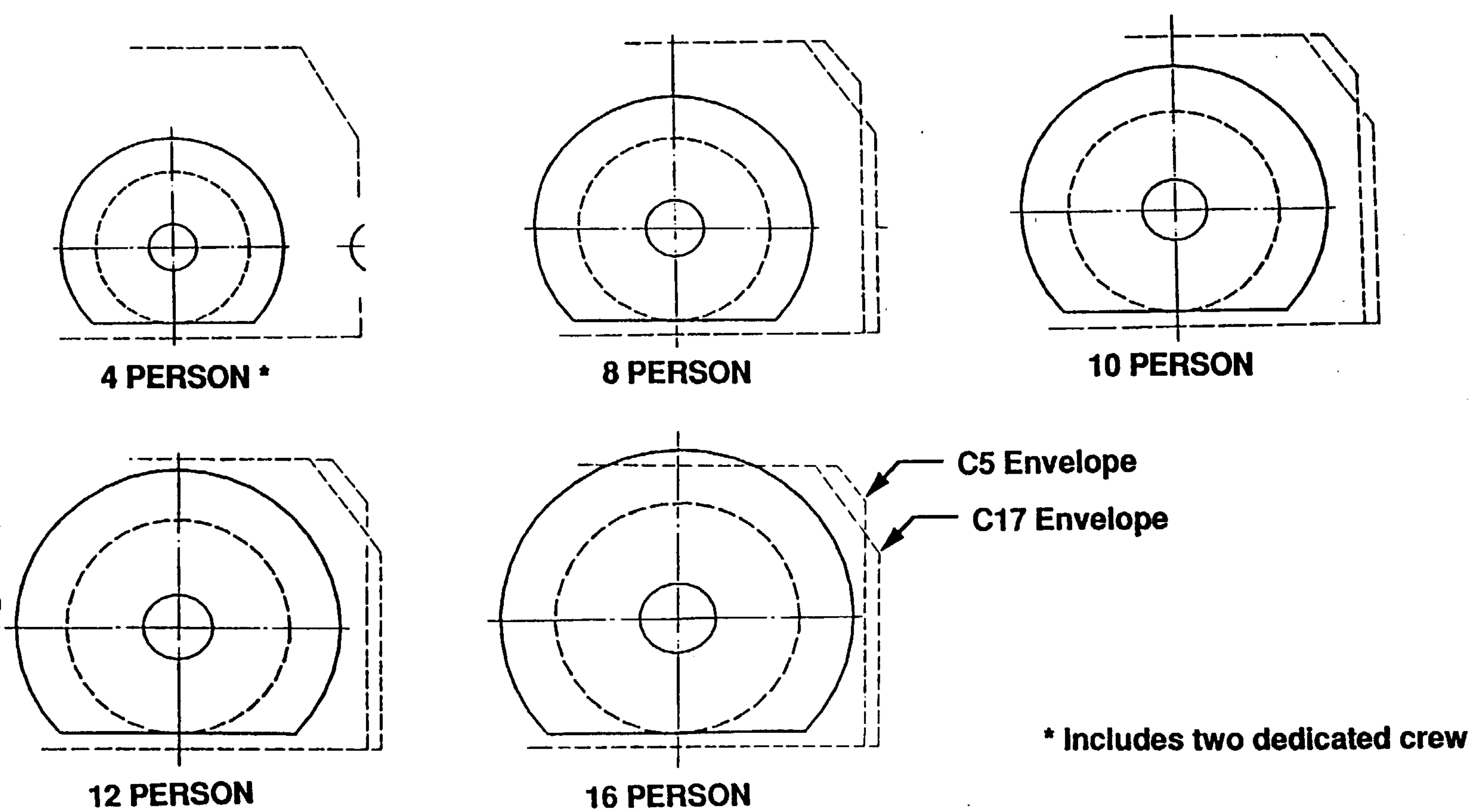
d) be transportable in the C-5/C-17.

5.1.2 Mission Duration

The effect of lengthening the mission is to provide increased capability and mission flexibility. Longer missions also tend to affect operations and fleet size. From a design standpoint, longer missions require more consumables and more interior volume.

Figure 5.1.2-1 depicts the consumables growth with increasing mission duration (detailed data can be found in Table 5.1.2-1). Note that, in some cases, the choice of subsystem type can change for a different mission length.

When determining the appropriate volume to be allocated to the PLS crew/passengers, two areas of consideration were: a) anthropomorphic constraints such as orientation, restraint, and clearance, and; b) psychological considerations related to the crew being in confined spaces for a significant period of time. The first consideration is addressed by subjecting the design to standards such as NASA 3000



BICONIC COMPATIBLE WITH AIR TRANSPORT FOR UP TO 12 PERSONS

Figure 5.1.1-6. Personnel Load Impact on Transportability

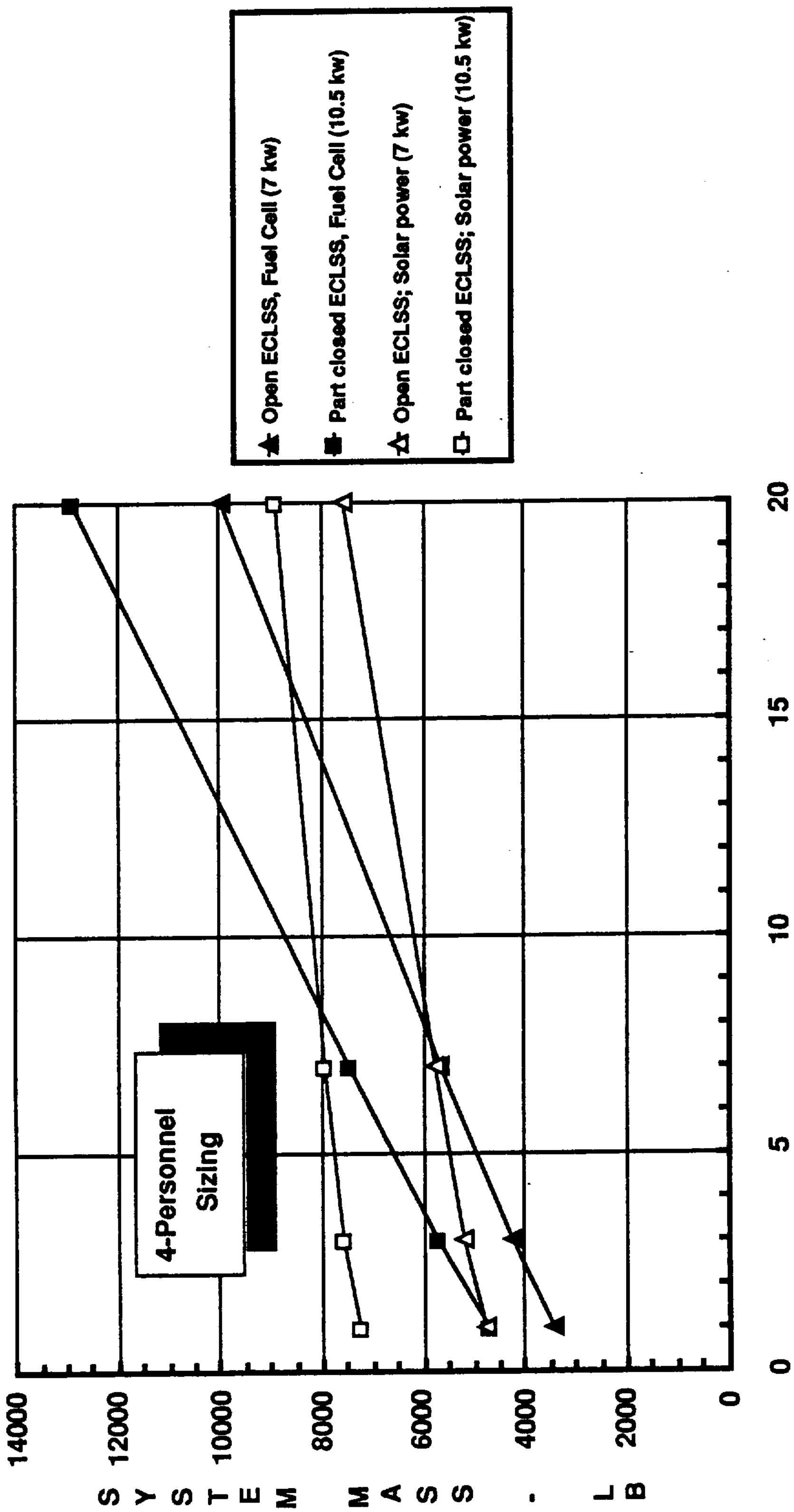


Figure 5.1.2-1 Consumables Mass versus Mission Duration

Table 5.1.2-1 Consumables Mass Comparison/Mission Duration (Page 1 of 2)

POWER, ECLSS WEIGHT COMPARISON	PERSONNEL LAUNCH SYSTEM
POWER SOURCE COMPARISON	MISSION DURATION TRADE

	ITEM	FUEL CELLS						SOLAR ARRAYS - LOW INCL					
		OPEN			PART CLOSED			OPEN			PART CLOSED		
		QTY	VALUE		QTY	VALUE		QTY	VALUE		QTY	VALUE	
	PERSONNEL			4			4			4			4
	CREW		2			2			2			2	
	PASSENGERS		2			2			2			2	
	MISSION DURATION (DAYS)			7.0			7.0			7.0			7.0
	NOMINAL		5.0			5.0			5.0			5.0	
	CONTINGENCY		2.0			2.0			2.0			2.0	
	POWER LEVEL - NOMINAL (KW)			7.0			10.5			7.0			10.5
	ECLSS												
	HABITABLE VOLUME (FT3)		736			736			736			736	
	PRESS/REPRESS EVENTS		2.0			2.0			2.0			2.0	
	CABIN LEAKAGE (%VOL TOTAL)		14.%			14.%			14.%			14.%	
4.0	POWER - ELECTRICAL			2096			2840			2754			3893
4.1	POWER SUPPLY			1073			1550			1680			2520
	FUEL CELLS		400			600			0			0	
	O2 TANKAGE		266			378			0			0	
	H2 TANKAGE		304			419			0			0	
	REACTANT PLUMBING		50			75			0			0	
	WATER STORAGE TANK		0			0			0			0	
	BATTERY		53			79			1190			1785	
	SOLAR ARRAYS		0			0			490			735	
4.2	POWER DIST EQUIP			315			315			315			315
4.3	WIRING			400			550			400			550
4.4	ELECTRICAL POWER SUPT/INSTL			268			362			359			508
2.3	FUEL CELL THERMAL CONTROL			42			63			0			0
	COOLANT PLUMBING		7			11			0			0	
	RADIATOR		35			53			0			0	
7.0	ENVIRONMENT			1482			2055			1593			2656
7.1	ATMOSPHERE PRESSURIZATION			144			479			144			479
	O2 TANKAGE	1	62		1	21		1	62		1	21	
	N2 TANKAGE	1	71		1	71		1	71		1	71	
	PRESS PLUMBING		12			12			12			12	
	WATER ELECTROLYSIS UNIT		0			375			0			375	
7.2	ATMOSPHERE REVITALIZATION			250			437			250			437
	CO2 REMOVAL		160			240			160			240	
	CO2 REDUCTION		0			107			0			107	
	HUMIDITY CONTROL		30			30			30			30	
	CATALYTIC OXIDIZER		40			40			40			40	
	DUCTING, MISC		20			20			20			20	
7.3	THERMAL CONTROL			595			595			595			595
	COOLANT LOOP		60			60			60			60	
	HEAT EXCHANGER		45			45			45			45	
	FANS		40			40			40			40	
	PUMPS, PLUMBING, ETC		50			50			50			50	
	RADIATOR		400			400			400			400	
7.4	FOOD MANAGEMENT			160			160			160			160

Table 5.1.2-1 Consumables Mass Comparison/Mission Duration (Page 2 of 2)

POWER, ECLSS WEIGHT COMPARISON POWER SOURCE COMPARISON	PERSONNEL LAUNCH SYSTEM MISSION DURATION TRADE

		FUEL CELLS				SOLAR ARRAYS - LOW INCL			
		OPEN		PART CLOSED		OPEN		PART CLOSED	
	ITEM	QTY	VALUE	QTY	VALUE	QTY	VALUE	QTY	VALUE
7.5	WATER MANAGEMENT		48		48		148		594
	POTABLE WATER STORAGE		13		13		113		42
	DIRTY WATER STORAGE TANK		0		0		0		42
	WATER TREATMENT SYSTEM		0		0		0		475
	WATER DISPENSER/ HANDWASH		25		25		25		25
	PLUMBING, VALVES, ETC		10		10		10		10
7.6	WASTE MANAGEMENT		150		150		150		150
	COMMODE		150		150		150		150
	WASTE STORAGE		0		0		0		0
7.7	ECLSS SUPT/INSTL		135		187		145		241
9.0	WEIGHT GROWTH MARGIN		537		734		652		982
	POWER, ECLSS DRY WT		4116		5630		4999		7531
12.0	NON-PROP CONSUMABLES		1536		1842		800		423
12.1	EPS FLUIDS		1072		1517		0		0
	USABLE O2		918		1304		0		0
	USABLE H2		117		161		0		0
	RESIDUAL REACTANT		37		53		0		0
12.2	ECLSS FLUIDS		464		325		800		423
	O2 - INITIAL PRESS +REPRESS		30		30		30		30
	O2 - INFLIGHT USAGE STORED		58		0		58		0
	N2		101		101		101		101
	FOOD		112		112		112		112
	WATER - INITIAL CHARGE		42		42		42		42
	WATER - DRINKING, FOOD PREP		0		0		112		0
	WATER - PERSONAL HYGIENE		0		0		224		98
	LIOH CANISTERS		91		0		91		0
	WASTE MANAGEMENT		10		10		10		10
	EQUIP COOLING FLUIDS		20		30		20		30
A	TOTAL POWER, ECLSS WT		5652		7472		5799		7954
	total power		3484		4784		3167		4477
	total eclss		2168		2688		2632		3477

power	3484	4	8	10	12	4784	4	8	10	12	3167	4	8	10	12	4476.9	4	8	10	12
	1	1697	1876	1954	2027	1	2274	2521	2628	2729	1	2944	3124	3202	3274	1	4170	4417	4524	4625
	3	2329	2573	2679	2779	3	3161	3498	3643	3780	3	3056	3300	3408	3506	3	4322	4659	4805	4941
	7	3484	3795	3930	4056	7	4784	5212	5397	5569	7	3167	3478	3613	3739	7	4477	4904	5089	5262
	20	7057	7474	7655	7825	20	9809	10383	10631	10864	20	3349	3768	3948	4117	20	4726	5300	5549	5782

ECLSS	2168	4	8	10	12	2688	4	8	10	12	2632	4	8	10	12	3476.9	4	8	10	12
	1	1757	1979	2088	2196	1	2450	2628	2716	2805	1	1823	2095	2231	2368	1	3091	3309	3418	3528
	3	1909	2284	2470	2655	3	2545	2818	2955	3092	3	2109	2666	2945	3224	3	3236	3599	3781	3963
	7	2168	2800	3116	3430	7	2688	3105	3313	3522	7	2632	3712	4253	4793	7	3477	4083	4385	4688
	20	2928	4322	5017	5826	20	3070	3868	4268	4781	20	4253	6954	8306	9771	20	4179	5486	6139	6907

(Reference 11). The second area of consideration is not nearly as rigorously quantitative, but has profound impacts on crew size and vehicle design.

A plot was produced showing the volume versus time ranges for historical manned flight vehicles (see Figure 5.1.2-2). Accessible volume is defined as the space available for human occupation (which excludes pressurized spaces such as the interior of storage lockers) and is shown as a volume per person figure. Time, or mission duration, is the period when humans could be expected to be confined in this volume. A broad general trend shows, as one would expect, that the longer the mission, the more personal space is found in existing designs. Previous studies have tried, without universal agreement or consistency, to quantify specific limits. In general though, it is obviously a design luxury to provide excess volume, and more typically one would try to design for the least required volume (and thus, usually, the lowest weight). The NASA STD 3000 data for volume limits (optimal, performance limit, and tolerable limit) is most useful for missions which are longer than most PLS missions. Historical data shown to the left of the trend (high volume/person) are typically development flights and are not representative of operational limits. Data to the right of the trend (low volume/person), while obviously possible, was produced by missions using specially screened, highly motivated crew on missions of historical significance - probably not what would be expected on every operational flight of a routine access transportation system. The physiological effects of spaceflight, including short mission duration effects have been studied extensively (References 12 and 13 are two excellent summaries).

The suggestion has been made that using a single PLS crew cab design for a variety of missions can be accomplished by simply offloading personnel for the maximum duration missions and filling the cabin with seats for the shortest missions. In general, this strategy will work, but further analysis reveals some other conclusions. Consider the three sets of lines drawn on Figure 5.1.2-2a. The solid lines represent a cab sized for 10 seats for a short-term occupancy mission converted to a 4 person vehicle used on a 7 day mission. Based on a preliminary timeline study (Reference 10), the nominal personnel occupancy time is about 14.5 hours (870 minutes) during ascent; the horizontal line represents a range of occupancy times from this data point to a maximum contingency of 3 days. While the volume does increase (per person) for the offloaded case, note that the original volume per person (three points at 32, 50, and 100 cubic feet as a bracket of possibilities) influences whether the longer duration

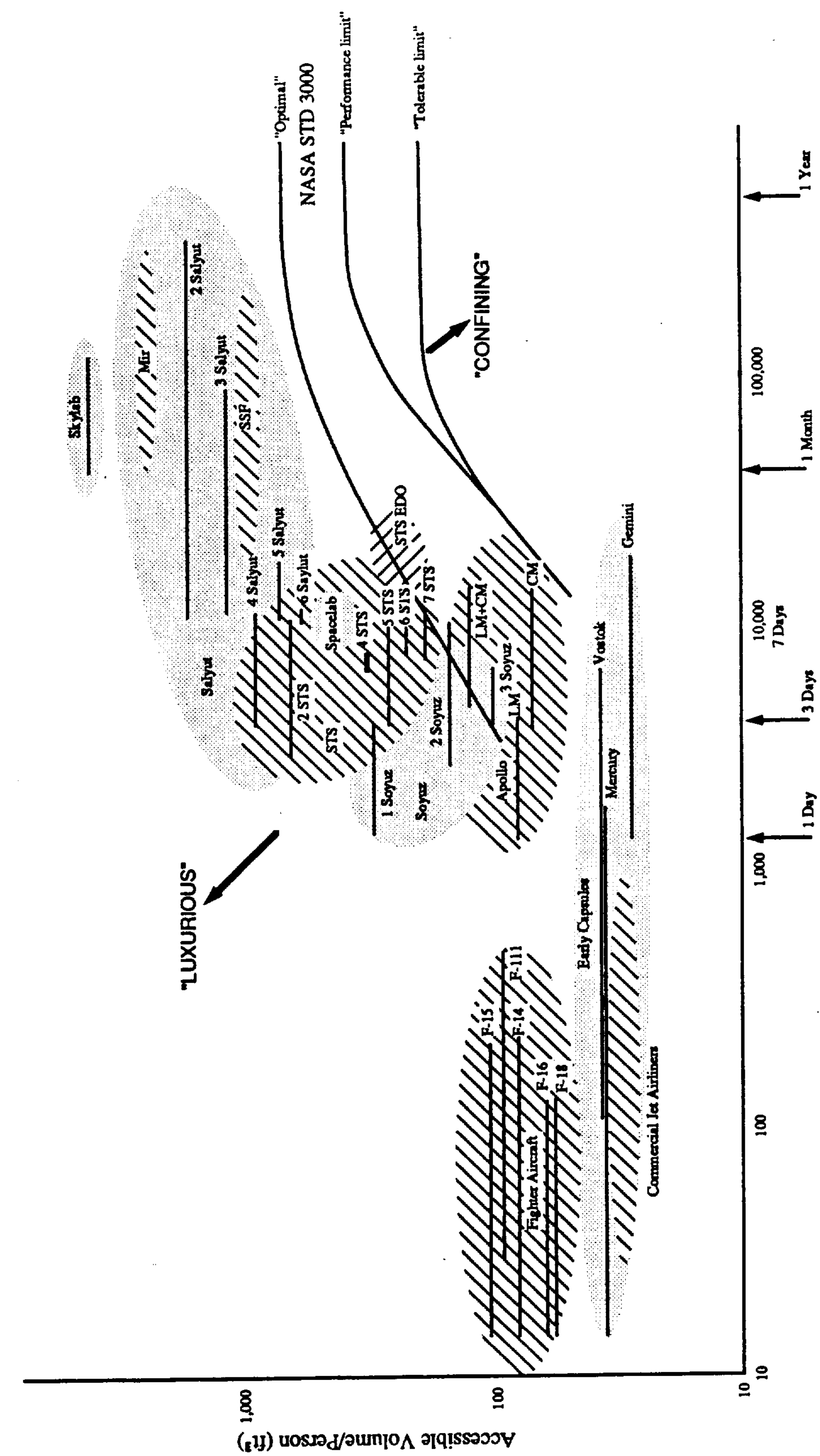


Figure 5.1.2-2 Available Volume per Person Versus Mission Duration

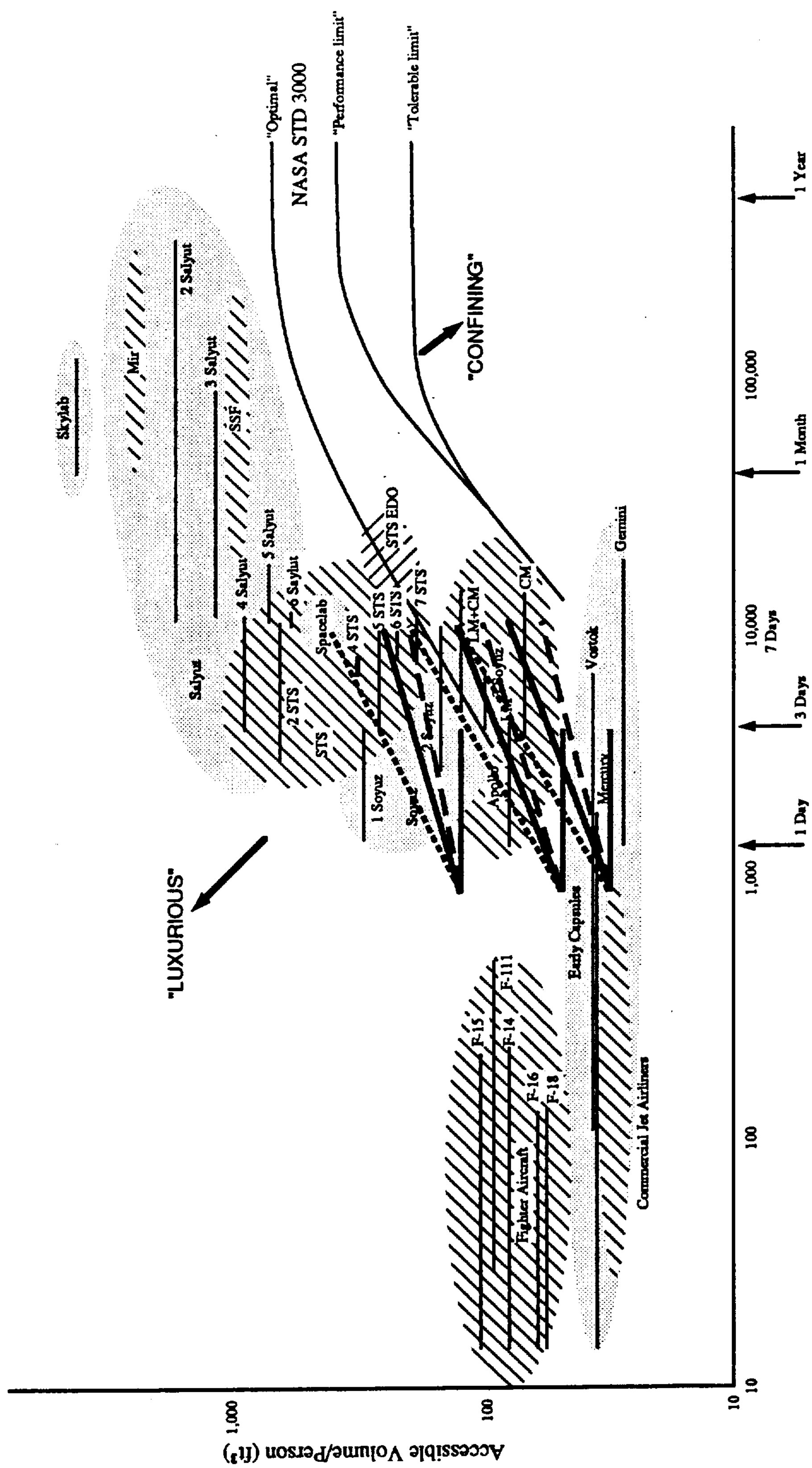


Figure 5.1.2-2a Mission Duration/Personnel Load Trade

mission is "comfortable". Likewise, the dashed curve represents 8 persons, and the dotted curve 16 persons.

So, what are the options for extending mission duration with the same PLS cab design? First, whether the crew size is the same or reduced as compared to the SSF rotation mission, an auxiliary living habitat could be docked to the PLS cab for long duration missions, increasing volume and perhaps consumables and amenities. If additional hardware is unacceptable, the curves lead to the following conclusions for the offloading person strategy: a) designing the cab for the highest number of people (with due consideration to the rest of the crew size trade) at any starting volume is the easiest way to ensure sufficient volume for longer missions, and; b) the larger the starting volume/person for any size crew, the more likely the offloaded crew version is to come within the volume limits on the chart.

5.1.3 Vehicle Life

Vehicle life refers to the number of flights or cycles that the airframe and/or the majority of subsystems are reused. Fully expendable solutions (Soyuz being an excellent example) can minimize certain operations and maintenance costs. Fully reusable systems, like commercial transports, offer lower acquisition costs. This trade will likely be repeated for each subsystem as the study progresses. At this point, the data shown assumes that the entire vehicle is reused or expended as a unit. Figure 5.1.3-1 shows an example of how vehicle life affects fleet size.

5.1.4 Turn-around Time

The time (manhours) involved in processing reusable hardware (for the non-expendable case) is directly related to operations costs, which are typically a high percentage of the overall LCC. Figure 5.1.4-1 shows an example of how variations in turn-around time impacts fleet size.

5.2 Entry/Recovery Trades

The following trades influence the aerodynamic shaping of the vehicle, as well as determine control system requirements. Operational procedures are also significantly impacted by these trades. Again, these trades are highly interdependent.

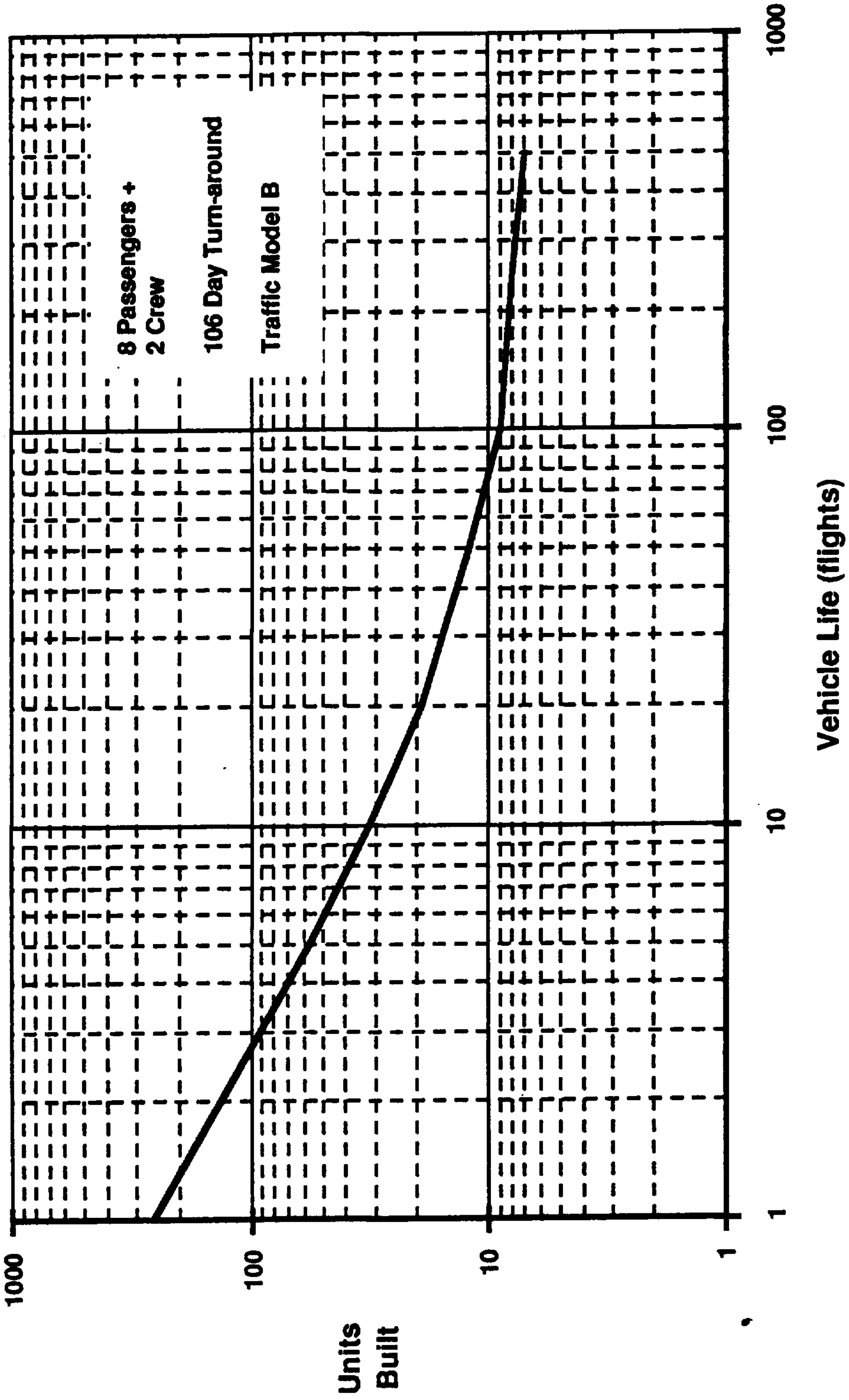


Figure 5.1.3-1 Example of Fleet Size versus Vehicle Life

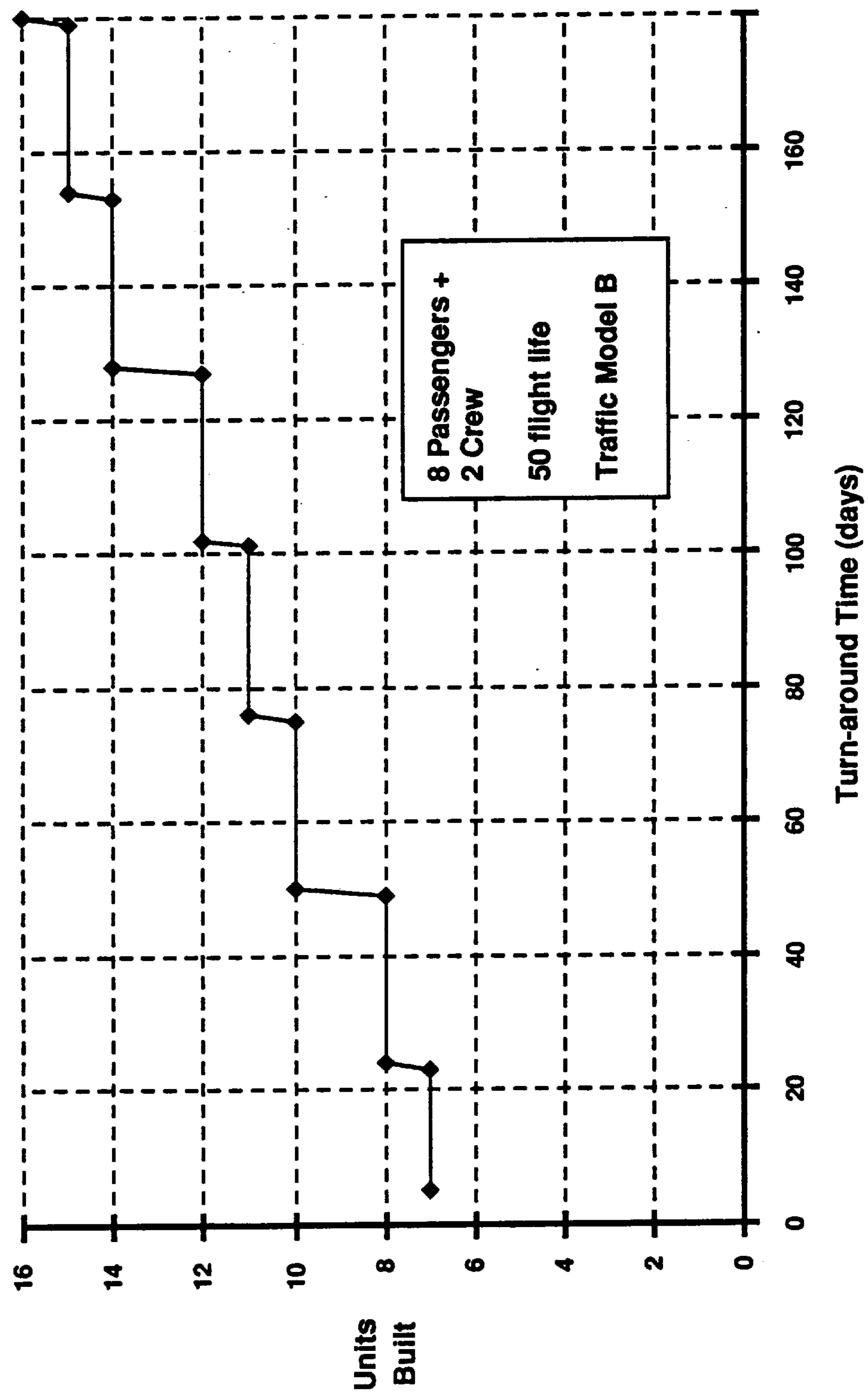


Figure 5.1.4-1 Example of Fleet Size versus Turnaround Time

5.2.1 Crossrange (L/D) Capability

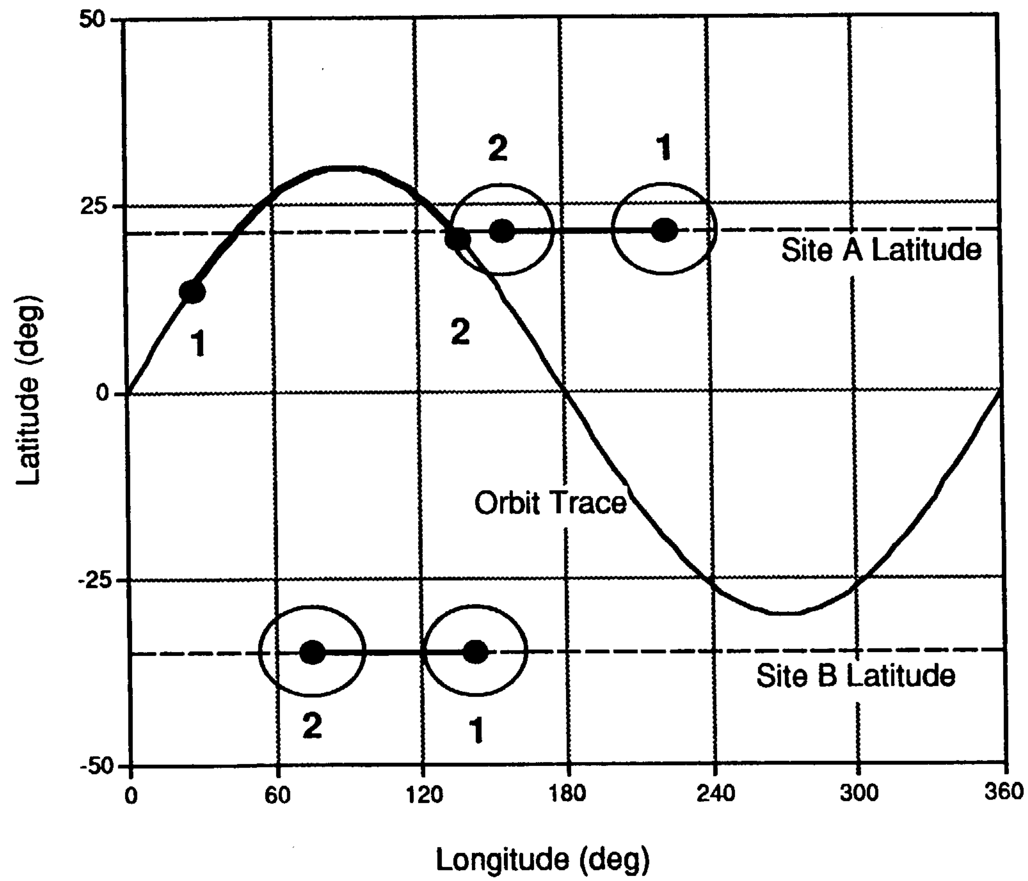
The performance capabilities (i.e. crossrange) of the vehicle and the operational constraints placed on reentry are the primary factors controlling the landing opportunities of the PLS vehicle. To minimize the operational costs of recovery, the ideal PLS vehicle would have to be able to land anywhere at anytime, however, this ideal PLS vehicle would be very expensive to develop and produce. The optimum design would trade the landing/recovery considerations to balance the development and production costs with the operational costs.

To aid in the determination of the optimum design for the PLS vehicle, a landing analysis trade was performed. The trade determined how landing opportunity varies with vehicle capability and reentry constraints.

While the PLS vehicle has many performance capabilities, some are more important than others for this study. The first is the crossrange (or "out-of-plane") capability. The more crossrange capability the vehicle has, the better landing sites can be reached at latitudes higher than the latitudes crossed by the vehicle orbit. More importantly, however, a large crossrange capability allows the vehicle to leave orbit sooner and more often. This is because the target in space through which the orbit must pass for the vehicle to deorbit and reach the landing site is a sphere with a radius equal to the crossrange capability. This is shown in Figure 5.2.1-1. The sample orbit of a PLS vehicle is shown with an inclination of 30 degrees. The latitude of random Site A is 20 degrees, less than the orbital inclination, while that of random Site B is -35 degrees, greater (magnitude-wise) than the inclination. The bullets indicate the positions of the vehicle and sites at times 1 and 2. The circles around the site bullets indicate the deorbit spheres which the vehicle must pass through to begin reentry. The larger the crossrange capability, the larger the circles, and the sooner the vehicle will pass through one. For this study, crossrange capability was varied from 30 nmi to 520 nmi.

The second important vehicle performance capability is orbital inclination; however this is primarily a capability of the PLS launch vehicle. The inclination nevertheless is the most important variable determining which latitudes can be reached and thus deserves to be studied. For this study, inclination was varied from 20 degrees to 100 degrees.

Sample Ground Traces of Vehicle and Landing Sites



- **Ground Rules**
  - **Assume ability to fly over landing site equals ability to deorbit and land there.**
  - **Probabilistic approach: initial vehicle position on orbit is unknown.**
- **Vehicle can land when it comes within crossrange distance of a landing site.**

Figure 5.2.1-1 Landing Analysis Theory

The third vehicle performance consideration is the orbital maneuvering capability, primarily that capability which affects the altitude and thereby the period of the orbit. Obviously, a vehicle which can maneuver has a better chance of intercepting a deorbit sphere than one which cannot. For this study, the initial altitude of the orbit was fixed at 250 nmi. The perigee was varied from 80 nmi to 250 nmi, while the apogee was varied from 80 nmi to 500 nmi (staying below the Van Allen belt).

There are many constraints that can be placed upon reentry which can greatly affect the landing opportunities of the PLS vehicle. Constraints which directly affect the vehicle (such as those to limit heating, structural loads, and passenger accelerations) eventually affect it's crossrange capability, and thus have already been accounted for. The remaining constraints affect the landing sites, chiefly the number and location of the sites and their availability. The greater the number of available landing sites, the sooner the vehicle can land.

As previously mentioned, orbital inclination is the primary variable determining which site latitudes can be reached. Thus the latitude of landing sites will impact the requirements for orbital inclination. The longitude of landing sites is also important, but for more subtle reasons. A few strategically-placed landing sites can greatly reduce the time required to land over a similar number of arbitrarily-placed sites. For the first part of this study, a single landing site (Kennedy Space Center) was chosen. For the second part, seven landing sites were chosen (see Table 5.2.1-1 and Figure 5.2.1-2). For the third part, four strategically-placed landing sites were chosen (see Table 5.2.1-2). This last part of this study was performed for the Assured Crew Return Vehicle (ACRV) program, but is included here for completeness.

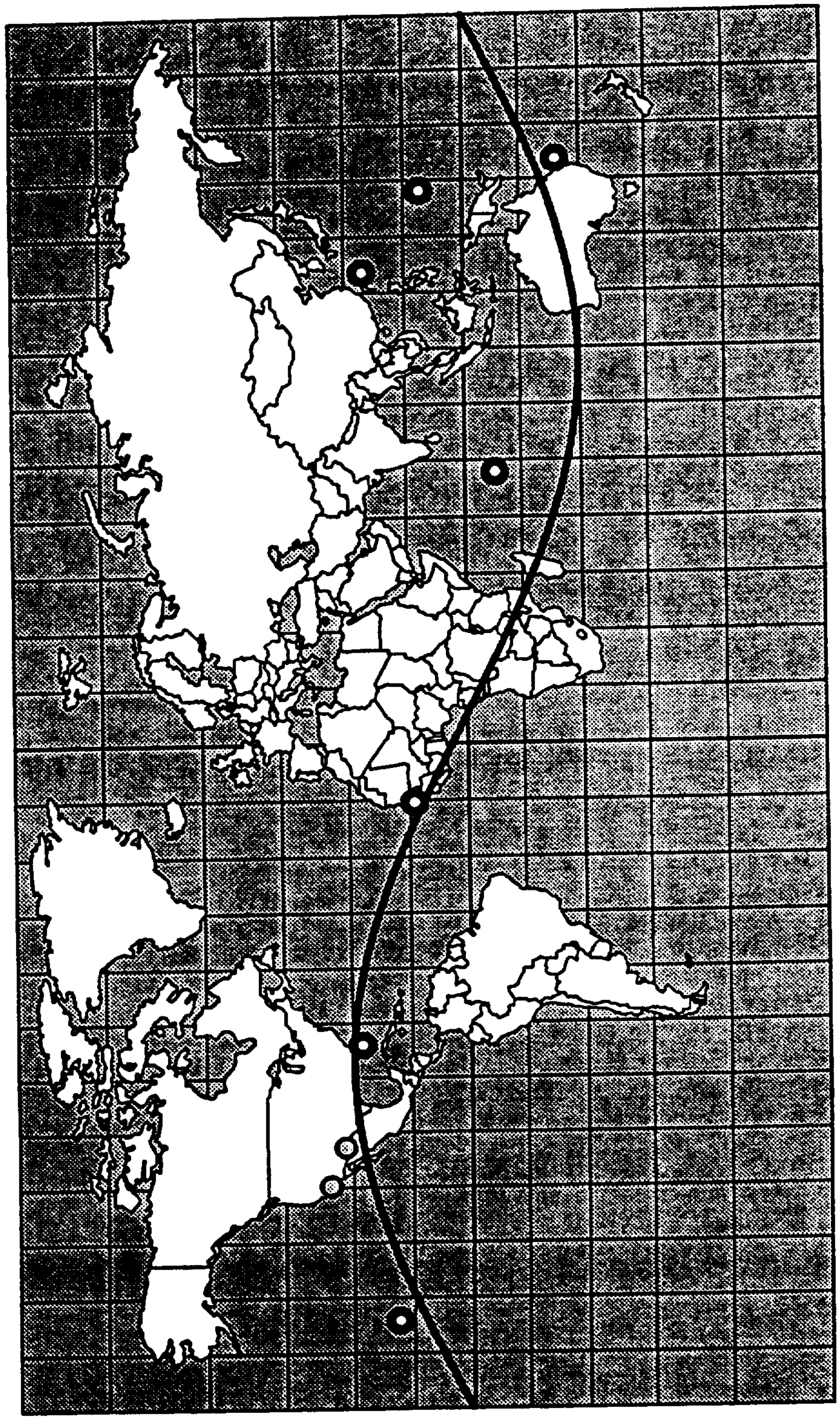


Figure 5.2.1-2. PLS Landing Sites

Site No.	Landing Site	Latitude	Longitude
1	Kennedy Space Center, FL	28.5 N	279.0 E
2	Dakar, African Coast	15.0 N	342.0 E
3	Diego Garcia, Indian Ocean	-7.0 N	71.0 E
4	Okinawa, China Sea	27.0 N	126.0 E
5	Guam, North Pacific	14.0 N	144.0 E
6	Fraser Island, Australia	-25.0 N	152.0 E
7	Hawaii, North Pacific	22.0 N	201.0 E

Table 5.2.1-1. PLS Vehicle Landing Sites

Site No.	Landing Site	Latitude	Longitude
1	Patrick AFB, Florida	28.6 N	279.3 E
2	Geraldton, Australia	-28.8 N	114.5 E
3	Kadena AFB, Okinawa	26.4 N	127.8 E
4	Florianopolis, Brazil	-27.5 N	311.5 E

Table 5.2.1-2. ACRV Landing Sites

The last constraint studied was site availability. This would include temporary site closure due to day or night landing restrictions on the vehicle or on recovery operations, legal restrictions on the operating hours of the site, and weather at the site. Permanent closure of a landing site would affect the total number of available landing sites, and thus has already been accounted for. For this study, two vehicle landing restrictions trades were performed, but no legal or weather restrictions were placed on

any of the sites. In the first trade, the vehicle could land at any site day or night. In the second trade, the vehicle could land at any site only during the day.

Approach - The purpose of the study was to determine the minimum on-orbit time a PLS vehicle required to reach the deorbit point for a landing site, regardless of its initial location on orbit relative to that site. The crossrange capability of the vehicle defines a sphere around the deorbit point with a radius equal to the crossrange.

A PLS vehicle in an inclined orbit about the Earth has only a small chance of intercepting the deorbit sphere for a landing site on each orbit. The oscillatory nature of the vehicle's orbit and the landing site's rotation with the planet create non-linearities which make it very difficult to analytically predict when and how often such intercepts will occur. For this reason, a computer simulation was created to numerically follow the vehicle in it's orbits and to determine when a deorbit sphere was intercepted.

For this study, a circular orbit of 250 nmi was specified, thereby defining the period of the orbit. The inclination would be varied as part of the trade, but the longitude of ascending node would be unknown. Also, the true anomaly (the initial position of the vehicle on the orbit) would be unknown. Because of this, a probabilistic approach was taken to solve the problem. Given all other parameters (crossrange capability and site location), the longitude of ascending node and the true anomaly were randomly selected. The simulation was then run and the minimum on-orbit time to intercept a deorbit sphere was computed. After a large number of runs (N), the resulting times were sorted from smallest to largest and plotted against probability ranging from 1/N to one. This procedure is shown in Figure 5.2.1-3.

Because the results were expressed in probabilities, an assumption was made to simplify the analysis process. It was assumed that the probability to intercept an on-orbit sphere above a landing site equalled the probability to intercept its deorbit sphere (which usually is about half an orbit back). This allowed the user to specify landing sites instead of their associated deorbit sites; and, basically, each simulation run would end when the vehicle passed over any of the landing sites.

For the day-only landing trades, the initial time of day also was unknown, and therefore had to be randomized. The time of year, which would control the angle of the terminator, however, was specified by the user.

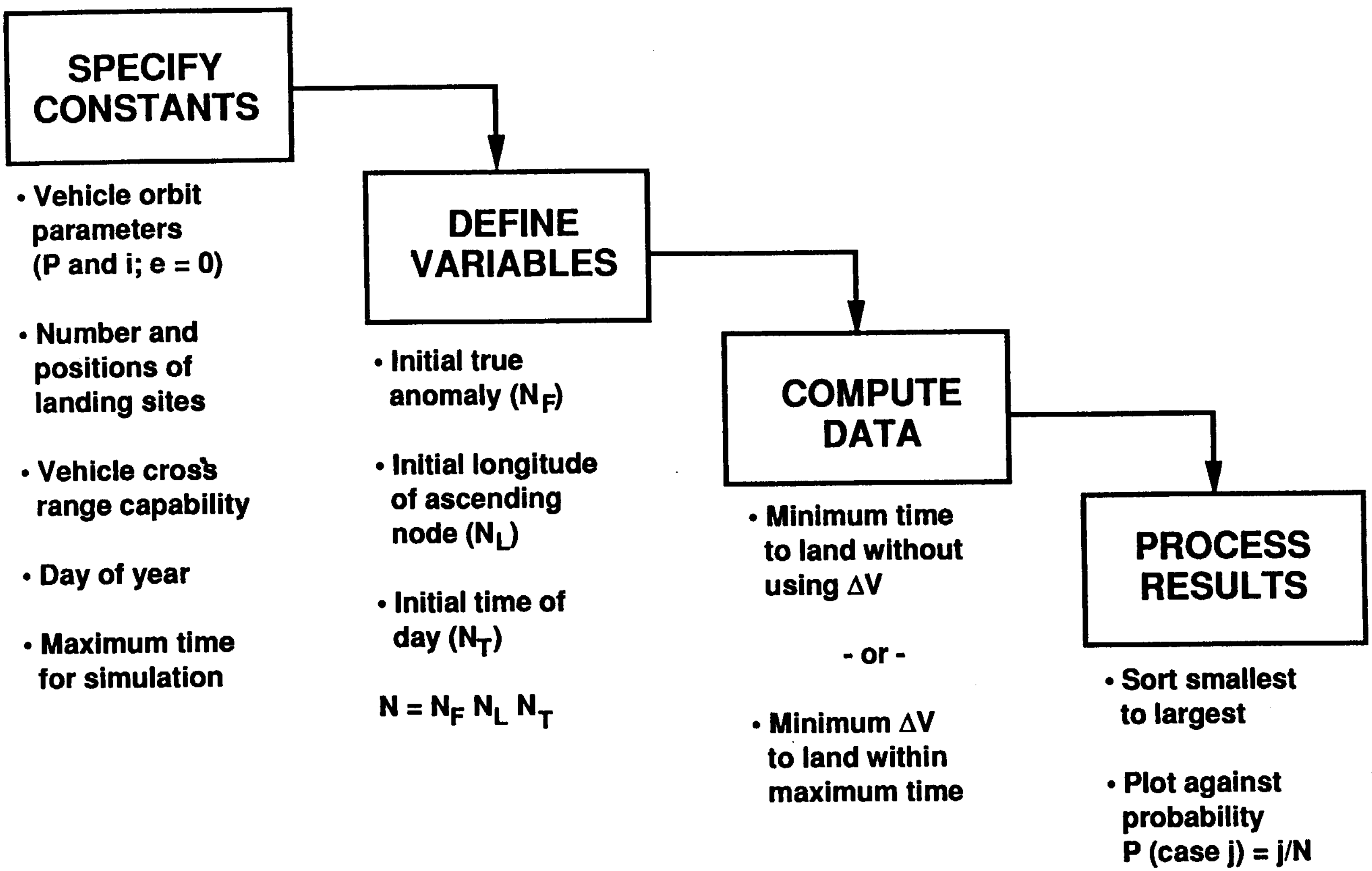


Figure 5.2.1-3 Landing Analysis Procedure

For the orbit maneuver trades, the desired minimum on-orbit time was specified by the user (in the form of the maximum simulation time). For each random run, the vehicle was first tested at its original altitude. If the required on-orbit time was less than or equal to that specified by the user, no ΔV would be required. If the time was greater, however, the orbit was perturbed until the required on-orbit time dropped below the specified threshold. The ΔV was then computed assuming the use of Hohmann transfers to perturb the orbit. A simplifying assumption was made that the perturbed orbit, although non-circular, had a constant angular velocity equal to its mean motion (as defined by its new period).

Methodology - Since the PLS vehicle travelled in it's orbit with a constant angular velocity, no numeric integration had to be performed to predict the position at a given time. Searching for the vehicle and landing site intersection proceeded at regular time intervals from time zero only to ensure that the first intersection would be found (which would then define the minimum on-orbit time). To determine when an intersection occurred, the following method was employed: first, take the dot product of the position vector of the PLS vehicle and each landing site. When any dot product, D_i, equals one, the vehicle has crossed exactly over a site. Since the vehicle only has to fall within a crossrange distance of the site, the dot product only has to be greater than some critical dot product, D_c, less than one: $D_i >= D_c < 1$ The critical dot product is defined as one minus the cosine of the crossrange angle (crossrange divided by Earth radius):

$$D_c = 1 - \cos \theta_c \quad \text{where} \quad \theta_c = R_c / R_E$$

The crossrange angle is also used to define the time interval. Since the vehicle orbits 2π radians per orbital period P, the time interval should be no greater than: $P\ \theta_c / 2\pi$. To ensure that no intersection slips through this numerical check, the time interval was set to half that value. Thus:

$$D_t = 1/2\ P\ \theta_c / 2\pi$$

Due to time and computer constraints, the total number of random runs per case was limited to around 1000. Thus, when day/night landings were analyzed, the number of initial longitudes of ascending node and number of initial true anomalies were each set to 31 (which yields 961 runs). When day only landings were analyzed, these numbers were reduced to 13 apiece, so that 13 initial times of day could also be

analyzed (which yields 2197 runs). Tests showed that, for this small number of runs, evenly dividing the values of initial longitude of ascending node, true anomaly, and time of day produced smoother results than those obtained by randomly varying them. Stepping through the values also ensured that all initial orbit positions and times of day were given an equal chance.

Results - The results of the study are shown in Figures 5.2.1-4 through 5.2.1-16. Figure 5.2.1-4 shows the probability of landing at Kennedy Space Center (KSC) versus on-orbit time (on a 250 nmi circular orbit, inclined 28.5°) for three different vehicle crossrange capabilities. By definition, the probability of landing increases with on-orbit time. The bend in the curves near the 2 hour mark is due to the vehicle, having completed one orbit (of about 93 minutes), subsequently flying over parts of the planet (due to the Earth's rotation) that could be reached on the previous pass. The bend near the tops of the curves is due to the vehicle running out of uncovered terrain as it makes it final passes.

Because the search for the minimum on-orbit time is numeric, there is a small chance that, even with the reduced time step, some first intersections may be missed. Most likely the second intersections will be found; however, since these occur at a later time, they get shifted to the higher probability slots during the sorting operation. This means that orbital time values very near to a probability of one, perhaps the last 10 or 20 in the sorted list, should not be trusted. For this reason, a probability of 99% was used, which corresponds to approximately the last 100th point in the sorted list. (A test was performed using a time step ten times smaller to prove that the 99% values could be trusted.)

Each curve in Figure 5.2.1-4 contains all the data computed for a PLS vehicle with a specific crossrange capability. Figure 5.2.1-5 shows the result of plotting orbital times for a few selected probability values against crossrange capability. For landing at KSC, the curves show only a small decrease in orbital time for even large increases in crossrange. (The 99% curve drops only 20% while crossrange increases an order-of-magnitude from 50 nmi to 500 nmi.) The tremendous jump in orbital time below a crossrange of 50 nmi shows what happens when the vehicle cannot land during the first 24 hours. Typically, the vehicle must wait almost another 24 hours for another landing opportunity. This figure shows very clearly the large penalty for having too low a crossrange capability.

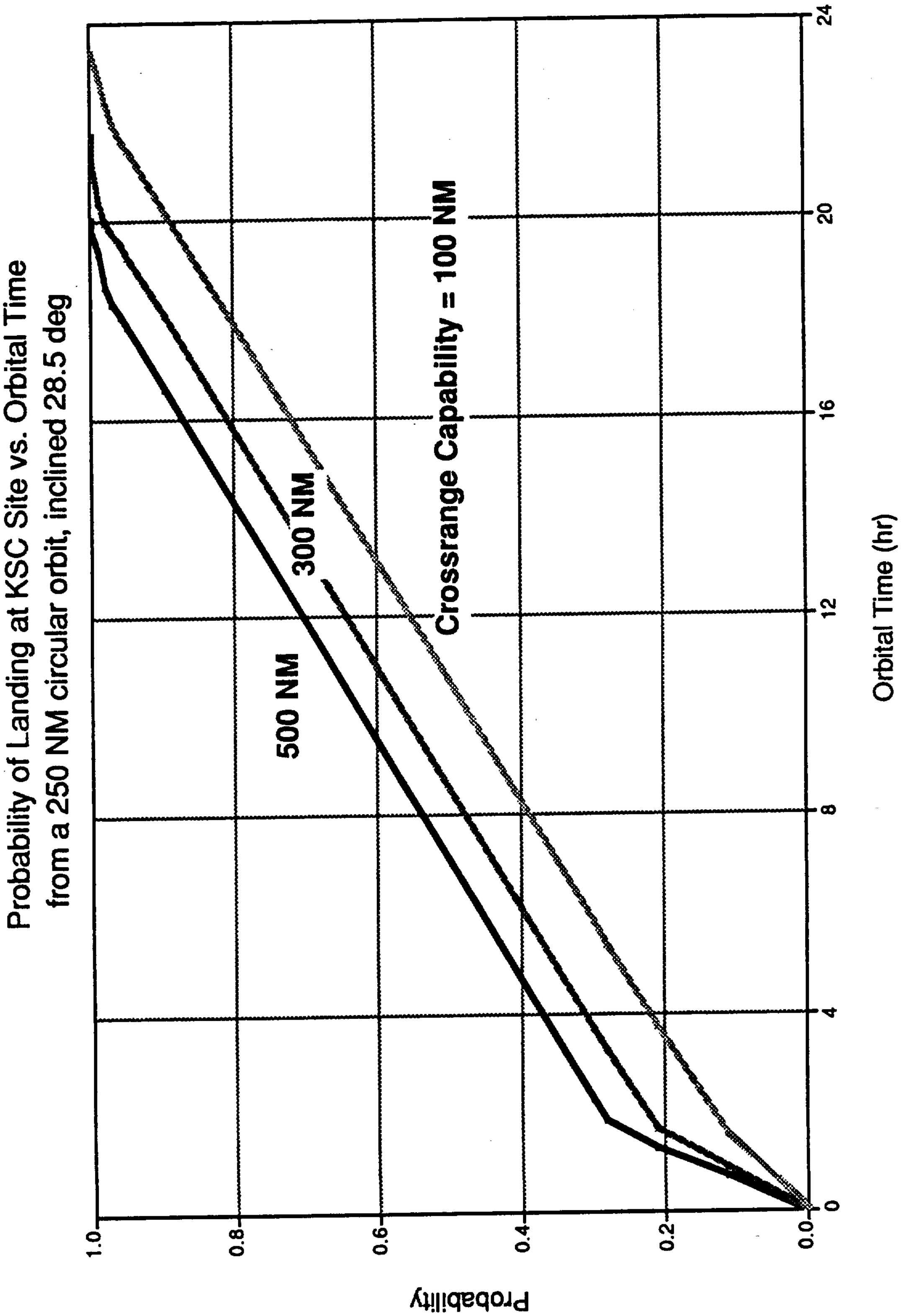


Figure 5.2.1-4 Landing Probability versus Time For a Single Landing Site

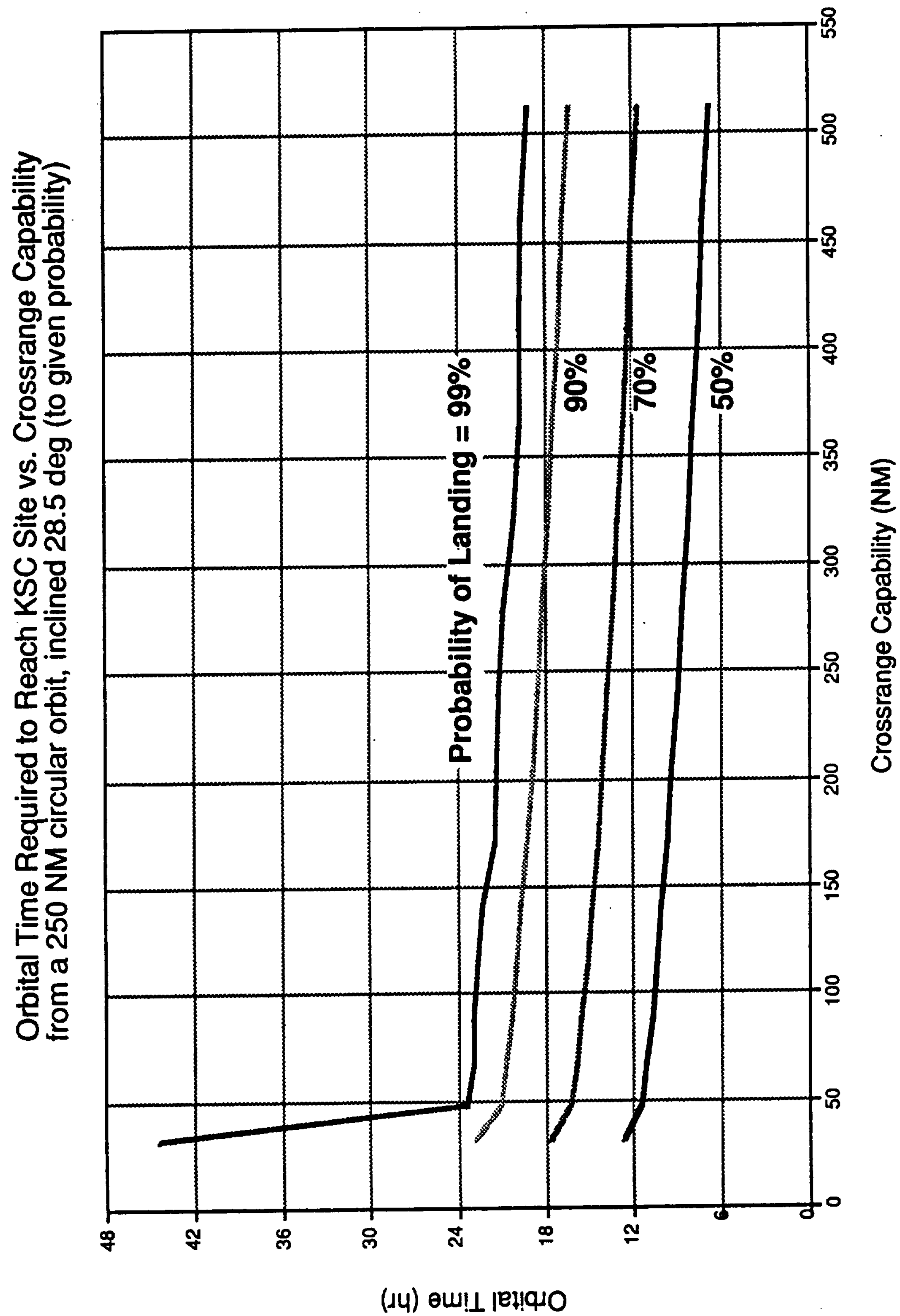


Figure 5.2.1-5 Time-to-Land versus Crossrange For a Single Landing Site

Figure 5.2.1-6 shows the effects of orbital inclination on landing; specifically, on landing at KSC 99% of the time. Orbital time is plotted against inclination for three crossrange capabilities. Values of inclination below the latitude of KSC were not studied. This figure shows that, up to a certain critical inclination value defined by the crossrange capability, the orbital time actually decreases with increasing inclination, although by only 10 minutes per degree. Beyond the critical inclination value, orbital time increases very rapidly, as much as 3 hours per degree, especially when a day (24 hour) boundary is crossed. This figure indicates that vehicle crossrange capability should be at least 300 nmi.

Figure 5.2.1-7 shows the effects of site availability on landing; specifically, on landing at KSC during the day as opposed to at any time. Day only probability values above 90% could not be achieved since the orbital time went beyond the maximum simulation time limit of five days. (And this was for a vehicle with a crossrange capability of 500 nmi!) This figure dramatically emphasizes the need to land the PLS vehicle during the first 24 hours.

The effects of different orbital altitudes on landing is shown in Figure 5.2.1-8. Since the orbital period was not changed much, this had very little effect on the orbital time required to land. Figure 5.2.1-9, on the other hand, shows the effects of changing orbital altitude using propulsion. Unlike the previous study where orbital altitude was fixed for all runs, in this study the altitude was changed for each run to minimize the orbital time to land. The maximum ΔV which could have been used was about 750 fps, which corresponds to lowering the perigee from 250 to 80 nmi, and raising the apogee from 250 to 500 nmi. The figure shows that using propulsion decreases orbital time to land at KSC by less than 10%.

Adding more landing sites makes a tremendous impact on orbital time. Figure 5.2.1-10 shows the probability of landing at any one of the seven sites listed in Table 5.2.1-1 versus on-orbit time (on a 250 nmi circular orbit, inclined 28.5°) for three different vehicle crossrange capabilities. Like Figure 5.2.1-4, there is a bend in the curves at the one orbit (93 minute) mark. Unlike Figure 5.2.1-4, however, the curves are not parallel. This also shows up in Figure 5.2.1-11, which plots the orbital time versus crossrange capability. Unlike the curve for the KSC site (shown for reference), which decreases fairly linearly with increasing crossrange, the curves for the 1 of 7 sites decrease exponentially. The opposite is also true, however; as crossrange capability

Orbital Time Required to Reach KSC Site vs. Orbit Inclination
from a 250 NM circular orbit, to 99% probability

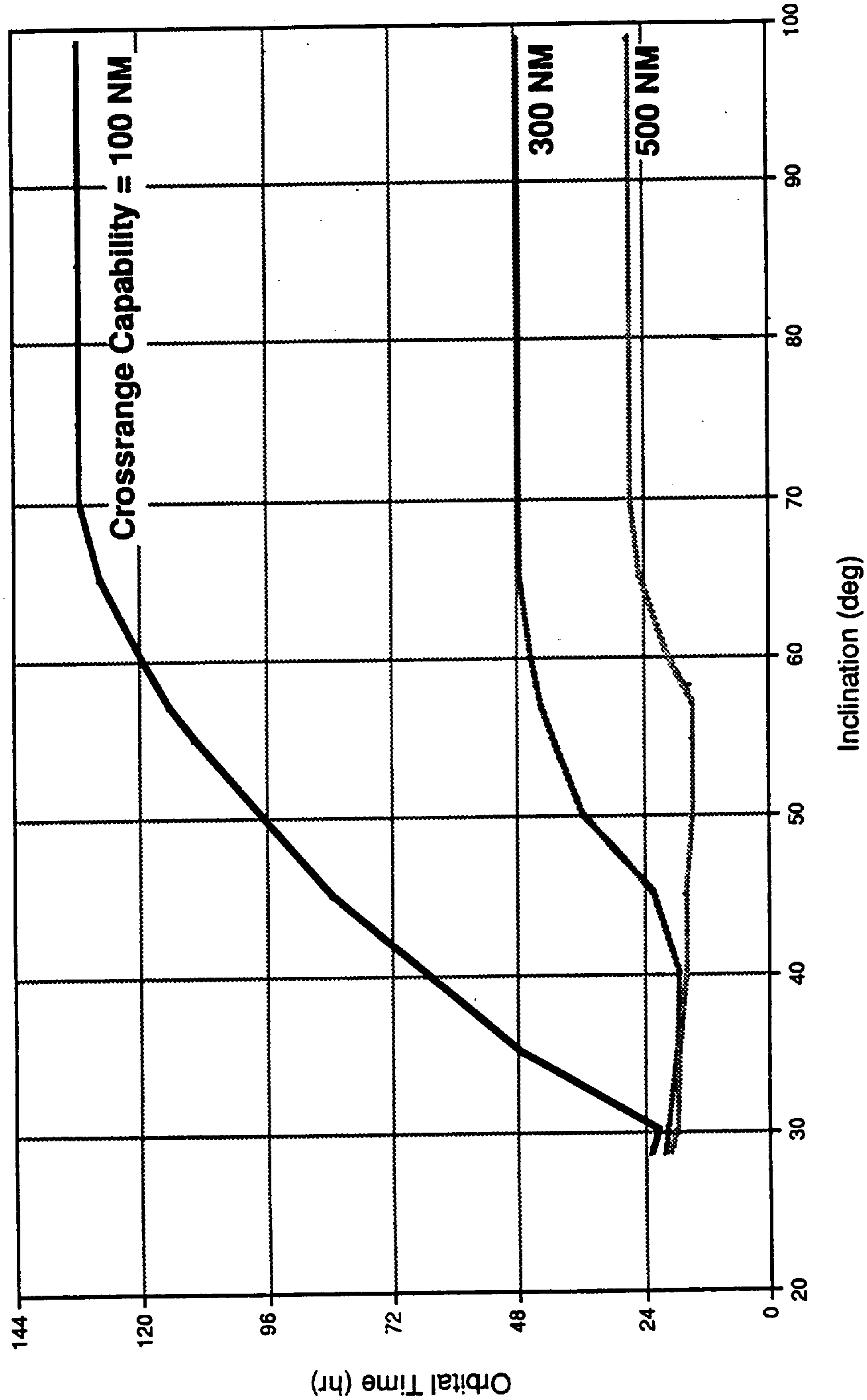


Figure 5.2.1-6 Time-to-Land versus Inclination For a Single Landing Site

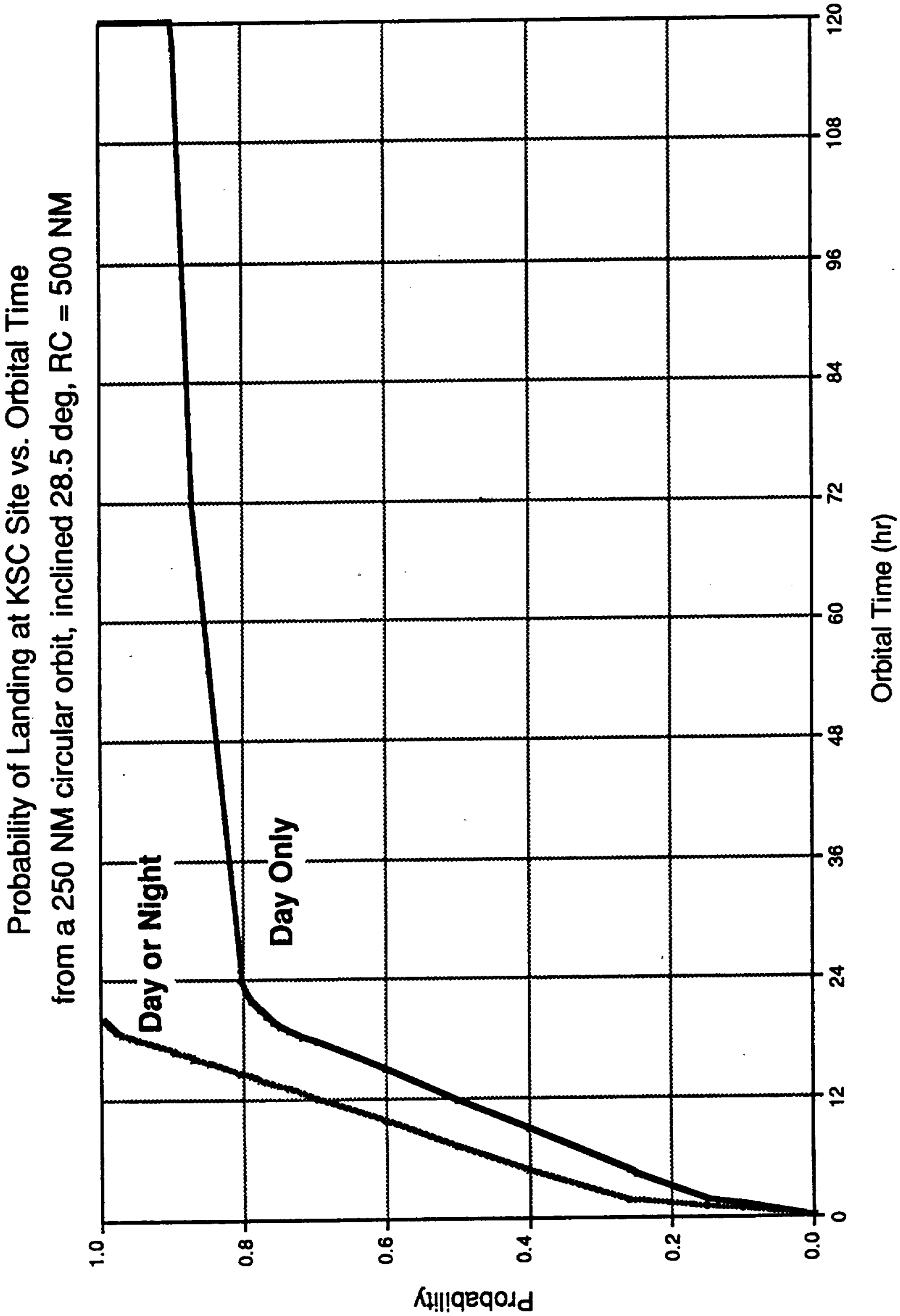


Figure 5.2.1-7 Day/Night versus Daytime Only Landings For a Single Landing Site

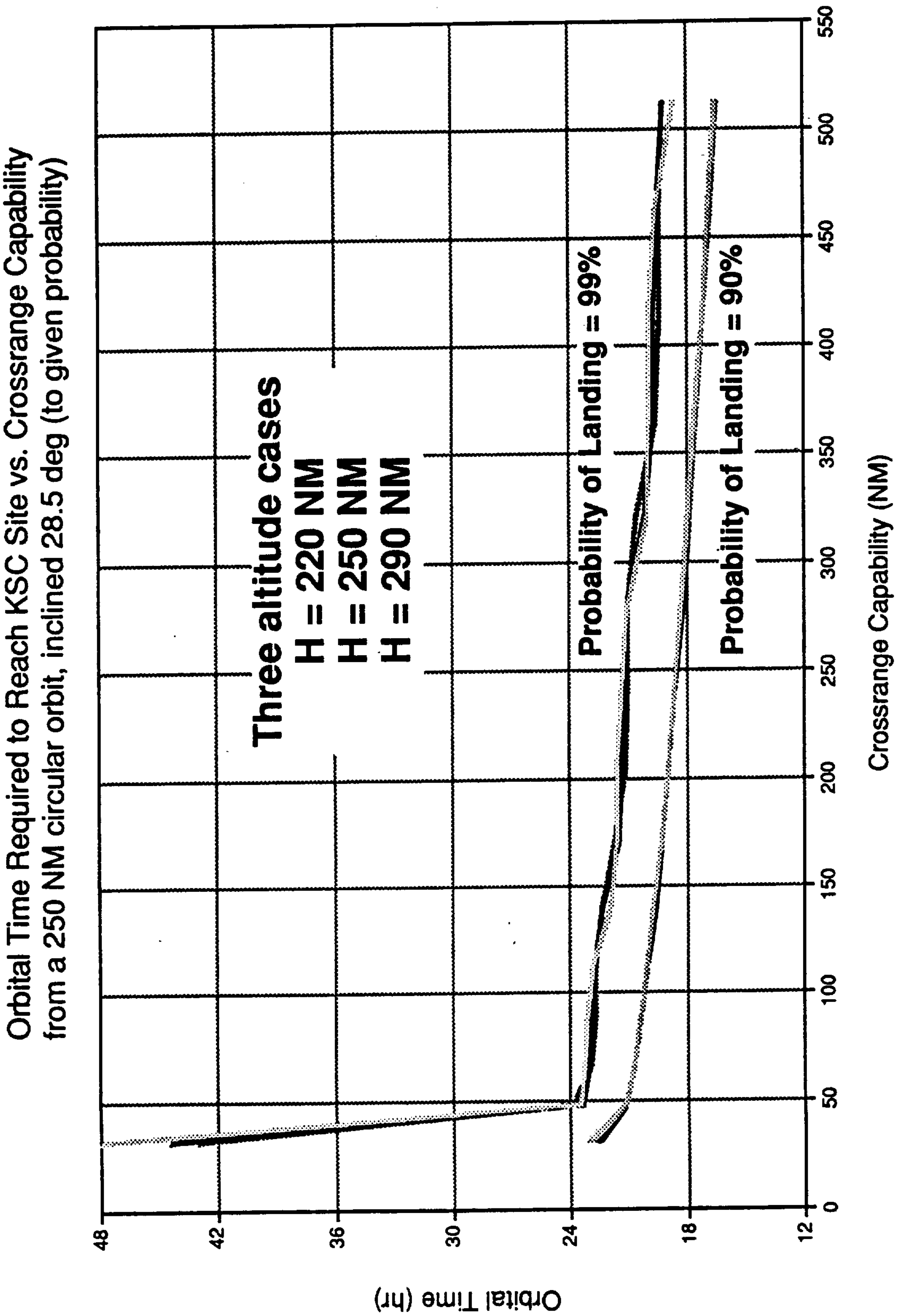


Figure 5.2.1-8 Effect of Orbital Altitude on Time-to-Land

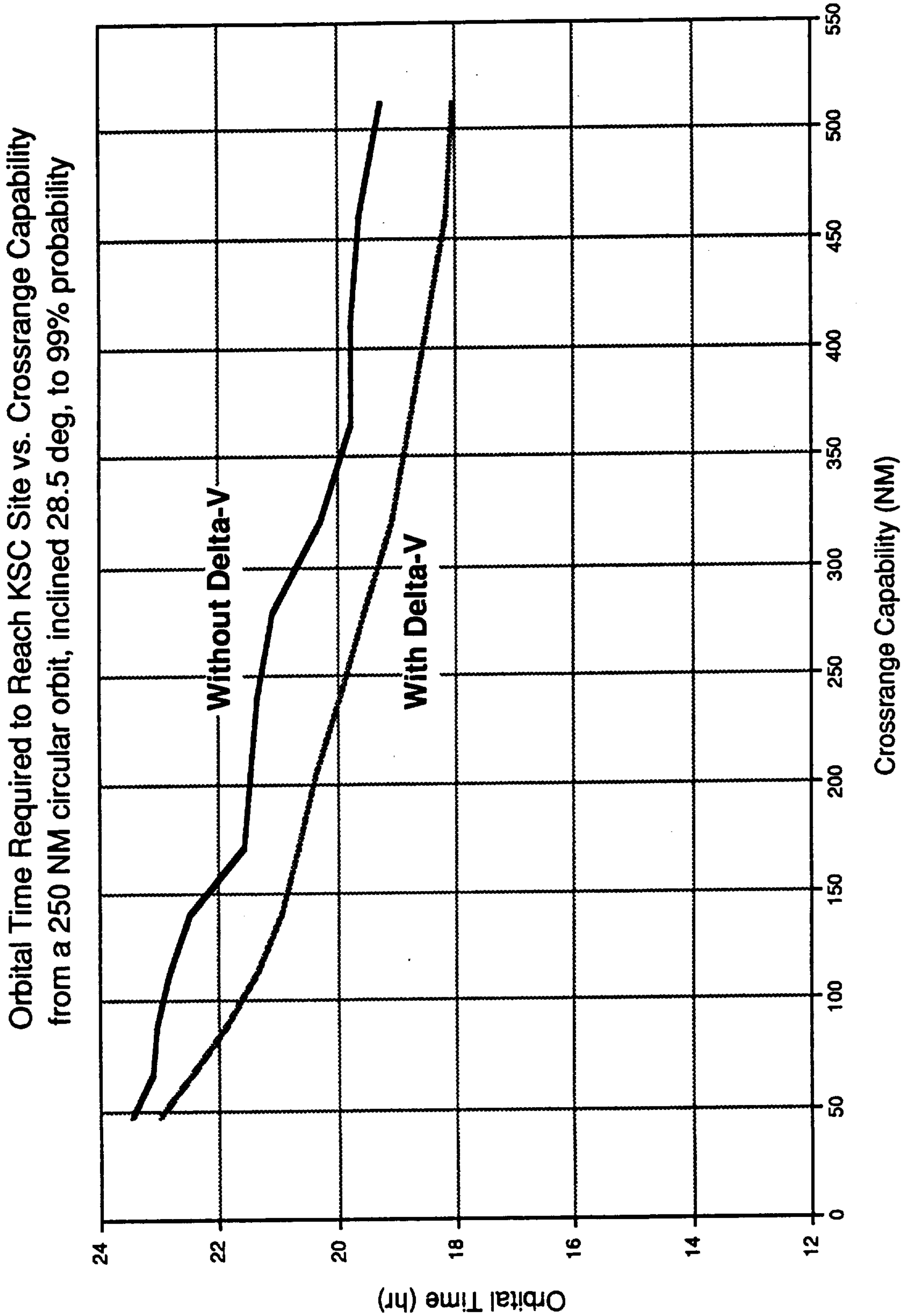


Figure 5.2.1-9 Effect of Orbital Maneuvers on Time-to-Land For a Single Landing Site

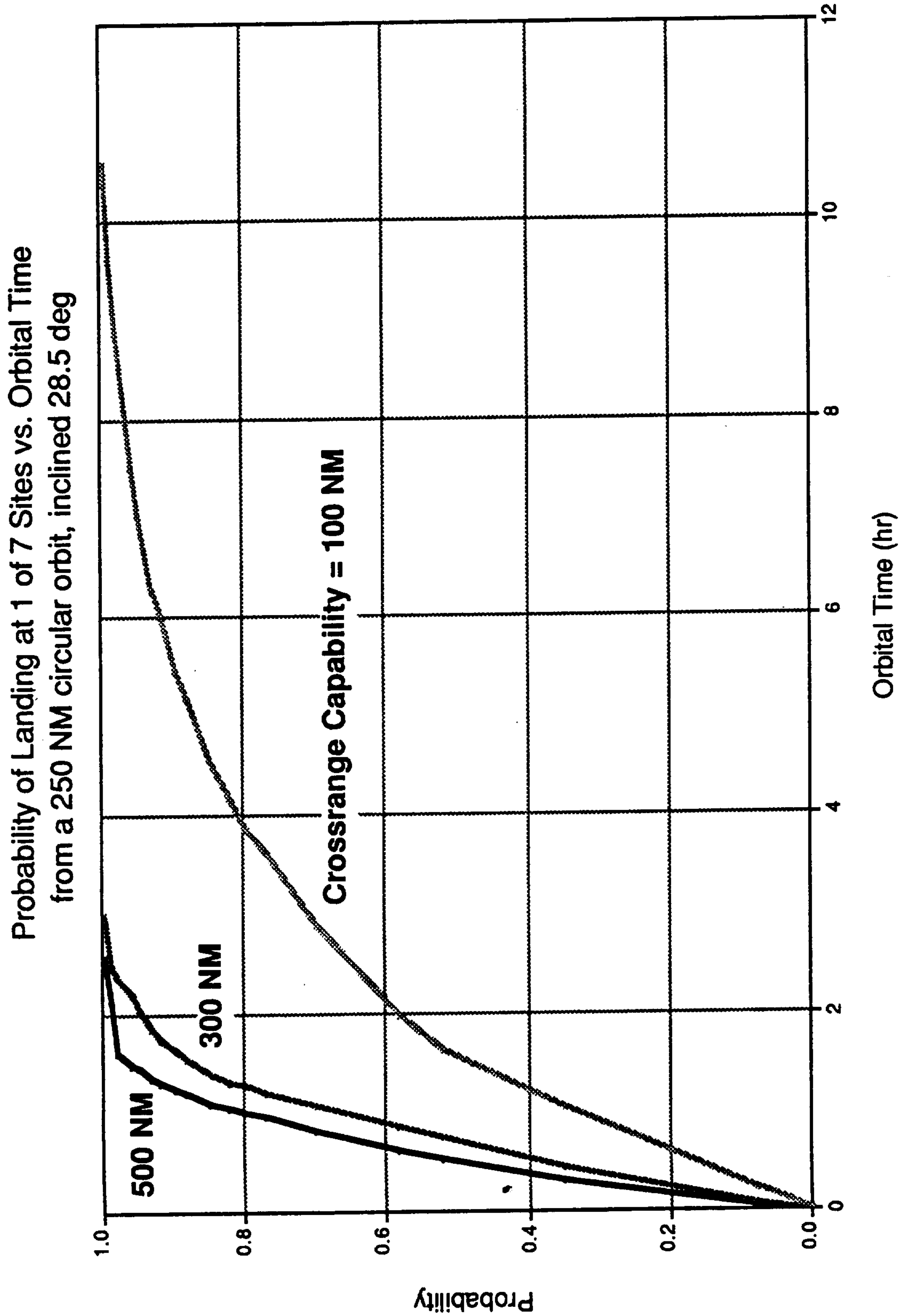


Figure 5.2.1-10 Landing Probability versus Time For Seven Landing Sites

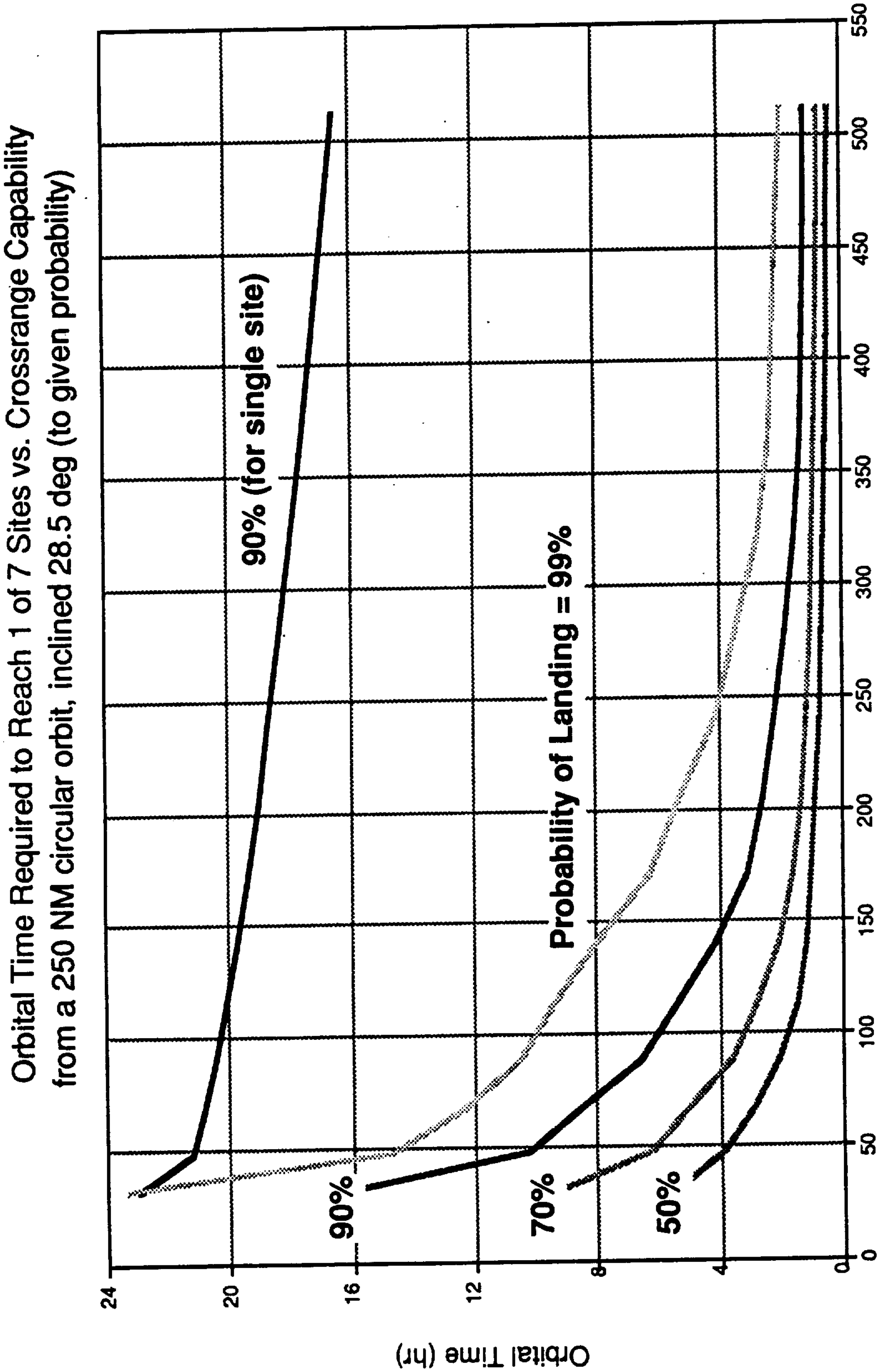


Figure 5.2.1-11 Time-to-Land versus Crossrange For Seven Landing Sites

drops below 300 nmi, the orbital time increases exponentially. Above 300 nmi, the orbital time decreases more linearly. Probably the greatest difference, however, is the drop in orbital time between landing at KSC and landing at 1 of 7 sites. Above 150 nmi, the vehicle lands 5 to 10 times sooner.

Figure 5.2.1-12 shows the effects of orbital inclination on landing at 1 of 7 sites. Values of inclination below a latitude of 20 degrees were not studied. Unlike Figure 5.2.1-6, this figure shows that the orbital time does not decrease as inclination is raised beyond the maximum latitude of KSC. Like Figure 5.2.1-6, however, this figure also indicates that vehicle crossrange capability should be at least 300 nmi.

Figure 5.2.1-13, like Figure 5.2.1-7, shows the effects of site availability on landing at 1 of 7 sites during the day as opposed to at any time. Since 99% probability values could be achieved, orbital time is shown plotted against crossrange capability. Above a crossrange of 150 nmi, orbital time for day only landings was about 8 hours longer than for day/night landings. Below 150 nmi, day only orbital time increased exponentially to several days longer.

Figure 5.2.1-14, like Figure 5.2.1-9, shows the effects of changing orbital altitude using propulsion to land at 1 of 7 sites. For very low crossrange capabilities, using propulsion reduced orbital time by as much as 30%. These crossrange values, as already seen, have other problems which make them unusable. More realistic crossrange values, those from 300 nmi and up, saw very little decrease in orbital time (less than 10%). The increase in crossrange capability had much more impact on reducing orbital time than does the use of propulsion. This figure also shows that while crossrange capability should be around 300 nmi or more, it does not need to be much above 400 nmi.

Landing site placement also affects time-to-land. Given a vehicle with a 300 nmi crossrange capability, Figure 5.2.1-13 shows that the orbital time required to land 99% of the time at 1 of 7 sites, at any time, is 2 hours; and during the day only, is 11 hours. For landing at 1 of 4 strategically placed sites, the orbital time required to land at any time is 9 hours (7 hours more than 1 of 7); but during the day is 10 hours, only one hour more than its day/night counterpart, and one hour less than for the 1 of 7 case. By strategically placing almost half as many landing sites, the day only orbital time was reduced instead of doubled. This figure shows that when restrictions are placed on landing site availability, it pays to select them carefully.

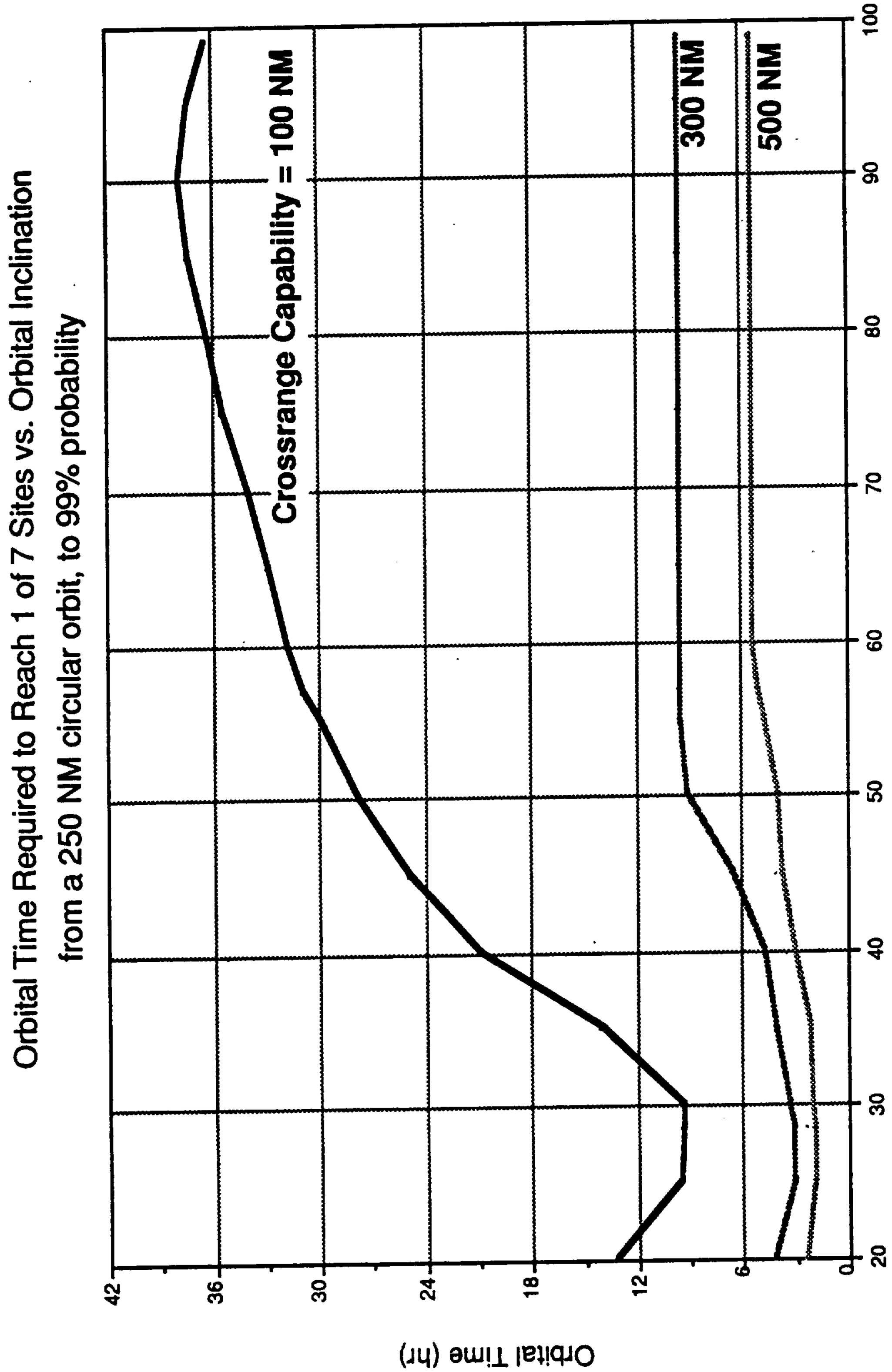


Figure 5.2.1-12 Time-to-Land versus Inclination For Seven Landing Sites

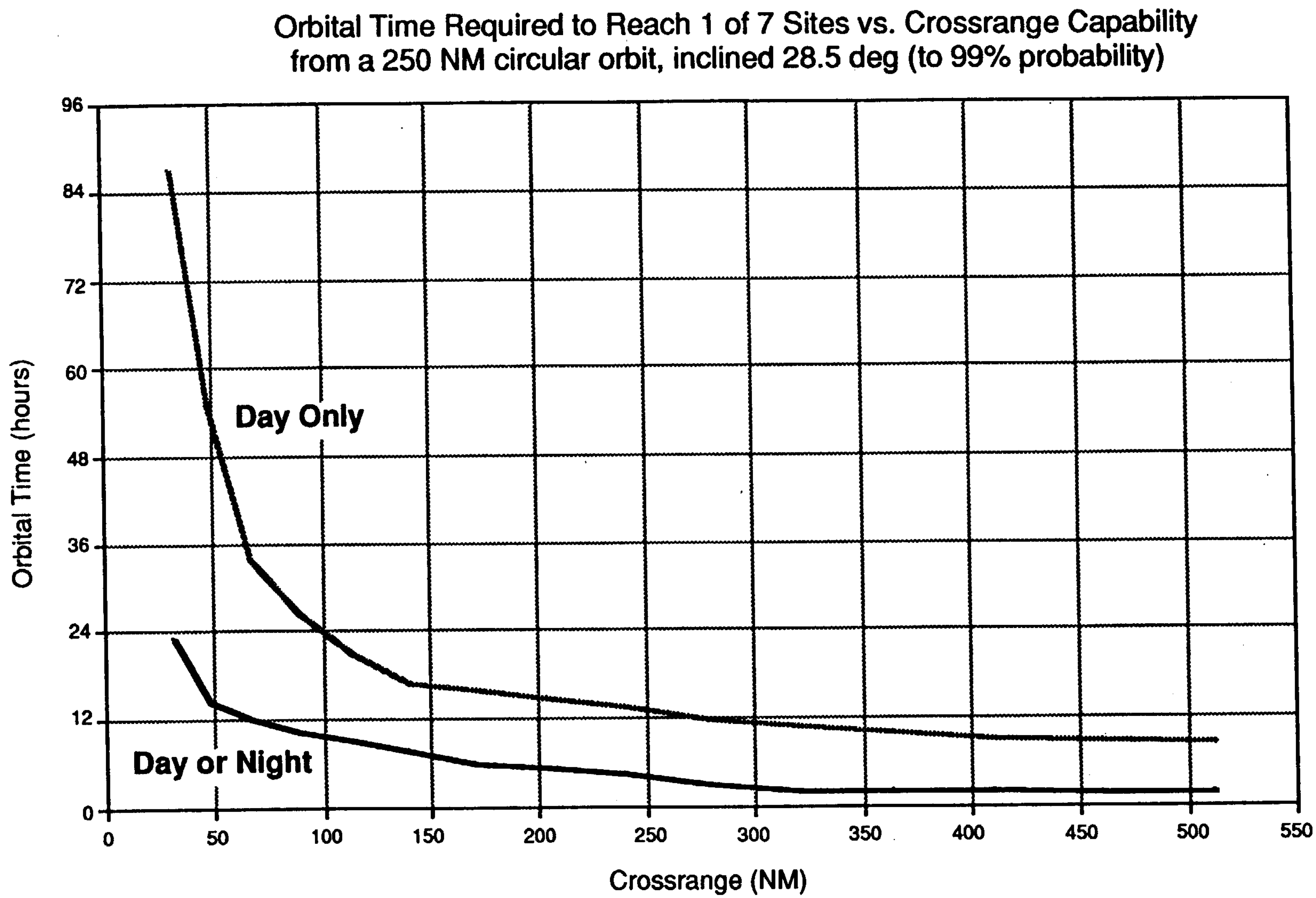


Figure 5.2.1-13 Day/Night versus Daytime Only Landings For Seven Landing Sites

Orbital Time Required to Reach 1 of 7 Sites vs. Crossrange Capability
from a 250 NM circular orbit, inclined 28.5 deg, to 99% probability

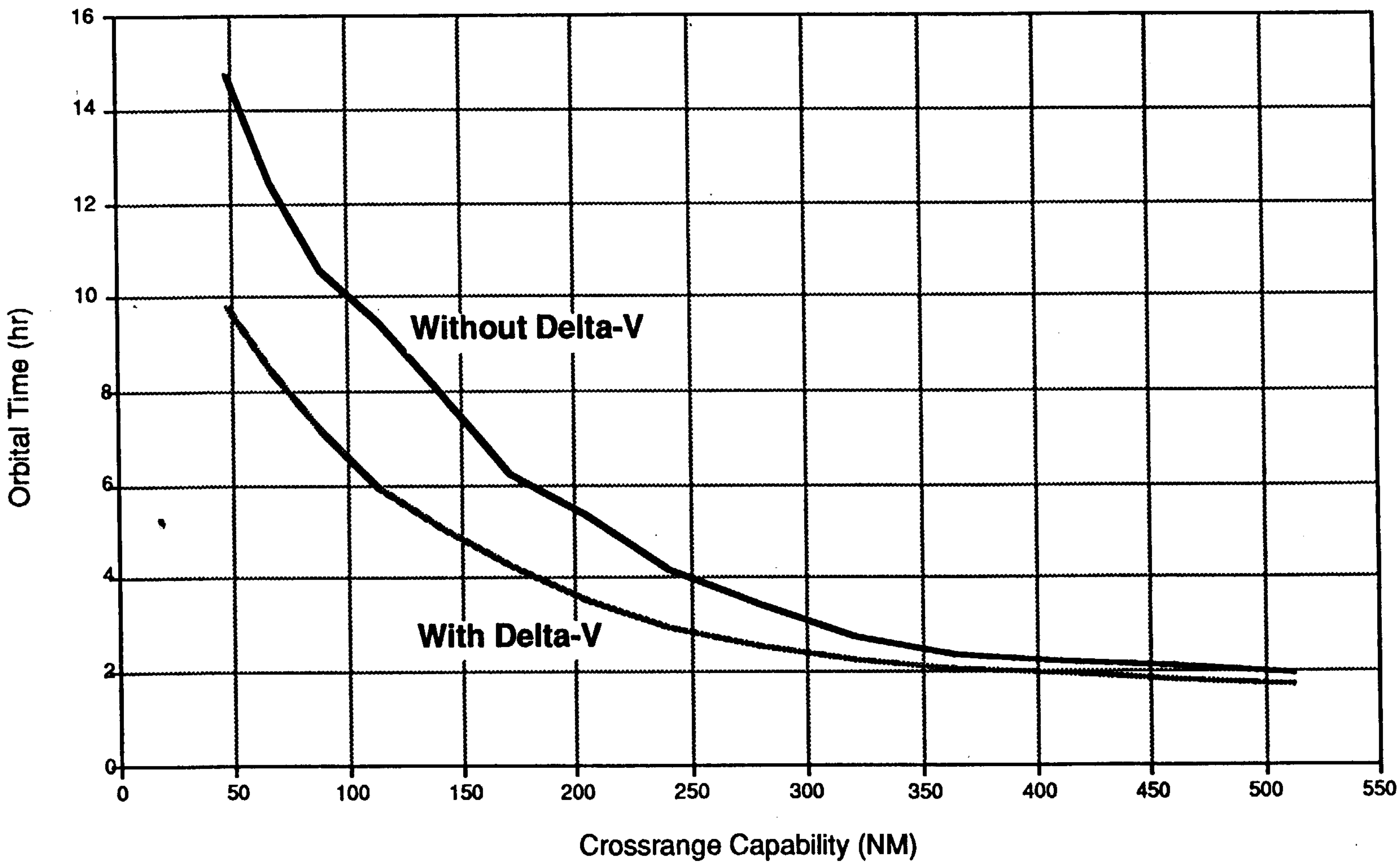


Figure 5.2.1-14 Effect of Orbital Maneuvers on Time-to-Land For Seven Landing Sites

In conclusion, unless a requirement exists to land immediately (within one orbit) at one prescribed landing site, a vehicle with limited crossrange capability (L/D greater than about 0.5) should be adequate to return crews in a timely fashion.

5.2.2 Entry Precision

The precision achieved during entry and atmospheric descent will directly influence the selection of recovery devices and sites. Guidance, navigation, and control, typically lumped together in one discipline, will each have a separate effect on the achievable precision. The challenge is to find a cost effective solution that enables operability under a range of conditions but requires a limited development program.

The guidance approach used to evaluate guidance precision for the PLS is similar to that recently developed and used for an ALS propulsion/avionics (P/A) module, which is also a large, low L/D reentry shape. The reentry phase of the guidance targets to an altitude, longitude, and latitude for beginning the terminal phase guidance. A nonlinear programming (NLP) guidance algorithm using bank angle only steering commands is used to steer the vehicle to the beginning of the terminal phase. The terminal phase guidance algorithm and the landing precision will depend on whether the terminal phase uses ballistic parachutes, steerable parachutes or some other method of landing.

The reentry guidance scenario will include the targeting of a deorbit burn, guidance during the deorbit burn, a coast to atmospheric entry, and bank angle steering down to the transfer to the terminal phase guidance. The guidance system design for the PLS will depend on the level of autonomy desired and whether an interface for manned intervention is to be included. The reentry heating and dynamic load constraints imposed on the PLS system may require active monitoring by the guidance system. Contingency planning and guidance accuracy requirements will be determined by the terminal phase design.

The navigation system will in all likelihood use GPS updates to maintain a small navigation system error. The contribution of the navigation system to the overall landing precision errors in modern systems is typically very small.

Controls for the vehicle consist of limited aerodynamic surfaces and reaction control jets. Previous studies, such as the ALS P/A module, have shown that the control

system will not contribute to the reentry precision of the PLS. However, the terminal phase and landing precision will depend on the terminal phase design concept.

The guidance approach used for analysis of the PLS is, as previously mentioned, a NLP algorithm. This algorithm targets the nominal reentry trajectory to limit the aerodynamic loads and heating on the vehicle during reentry. For analytical purposes, a constant L/D vehicle model was used with bank angle only steering to the targeted terminal phase handoff. The initial targeting for the trajectory was with a winter season mean Global Reference Atmospheric Model (GRAM88) density and wind profile. The algorithm was then tested using random atmospheres generated by the GRAM88 program. Figure 5.2.2-1 is an example of the atmospheric variations that were considered. The type of guidance accuracies that are achievable using this guidance technique are shown as Figure 5.2.2-2. This data is for an ALS P/A module and although a PLS would have a different ballistic coefficient and L/D, the dispersions would be similar.

The guidance targeting was designed to follow a performance design trajectory. To indicate the range of performance available for the PLS vehicle, full lift up, full lift down, and no lift trajectories were flown (see Figure 5.2.2-3). Also, trajectories with and without wind were flown to determine the magnitude of the wind effects. The nominal guidance trajectory was designed to balance up and down range capability. The dynamic pressure, altitude, normal loads, and the cross range component are shown in Figure 5.2.2-4 through the mean GRAM88 mean winter atmosphere using guidance targeting, full lift up, full lift down, no lift, and guidance targeting with no winds. For 100 random GRAM88 atmospheres, the altitude, dynamic pressure, normal loads, and bank angle are shown in Figure 5.2.2-5. The guidance commands are calculated using trajectories projected from the current position to the target using the mean winter atmosphere.

In summary, using the techniques available for modern guidance algorithms, a level of entry precision can be achieved which enables even low L/D vehicles to land (depending on terminal landing concept) at predictable and relatively small landing areas (i.e. airfield-sized). This capability is largely a software development consideration - additional hardware is not required.

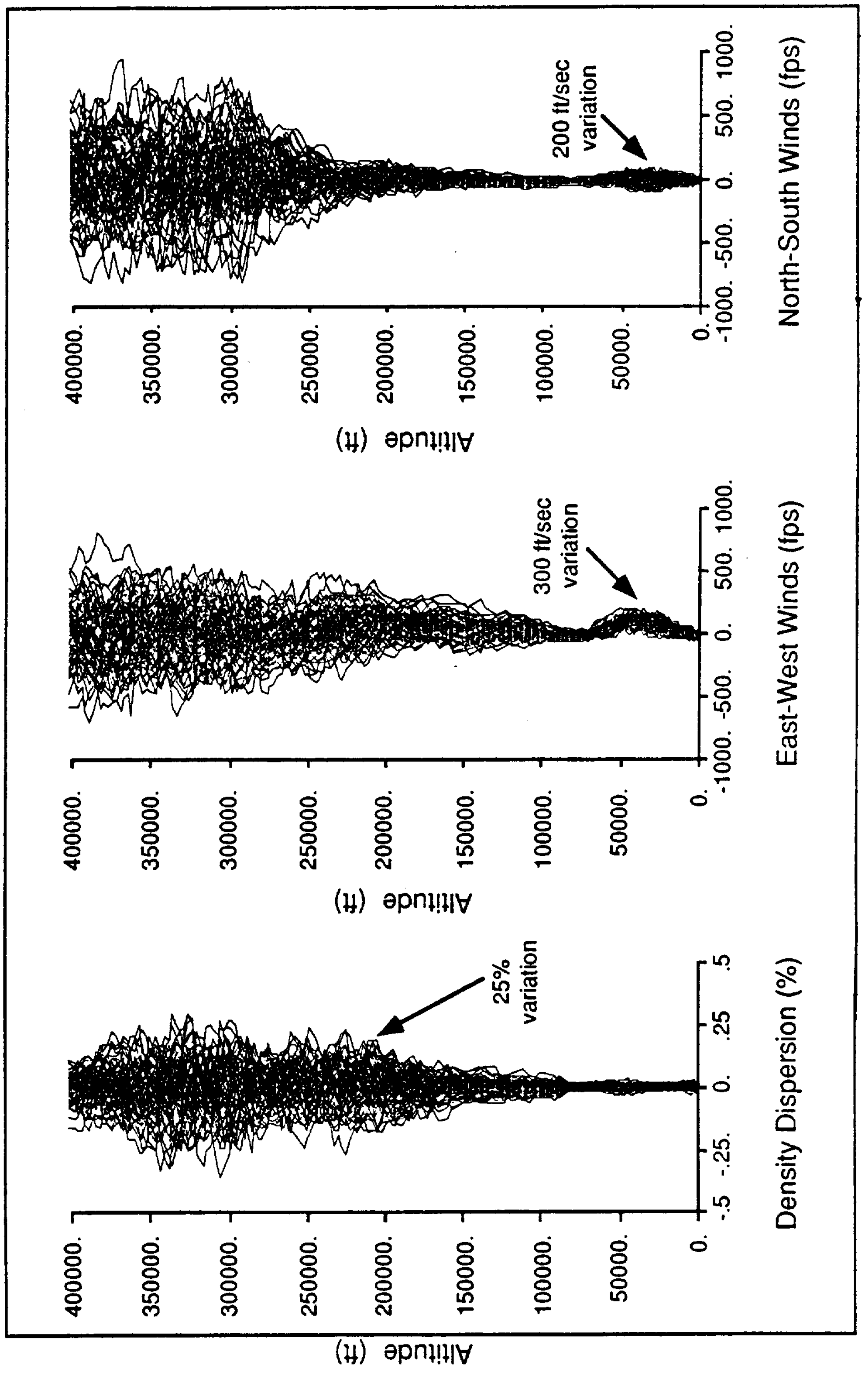


Figure 5.2.2-1 GRAM Random Density and Wind Profiles

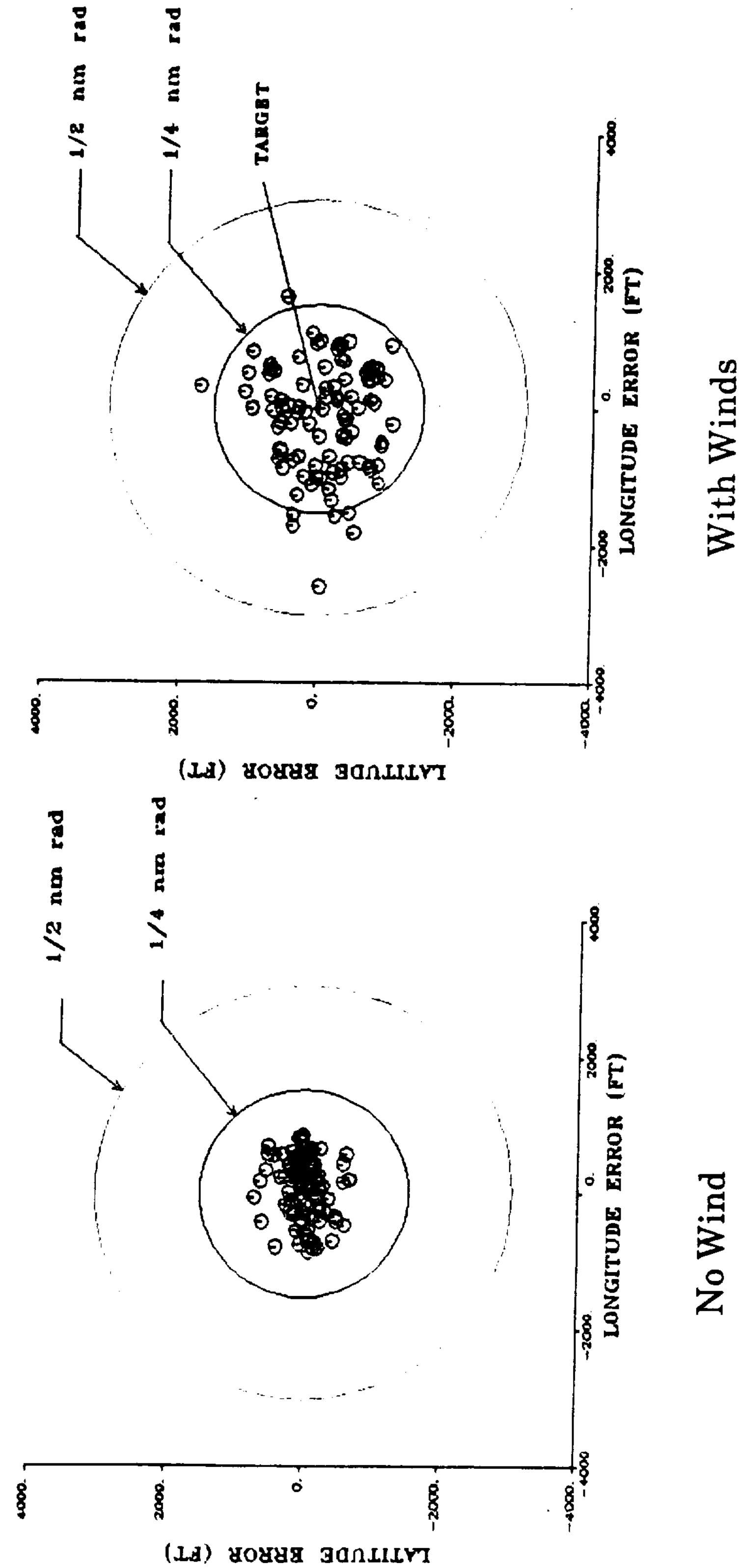


Figure 5.2.2-2 Typical Guidance Accuracy

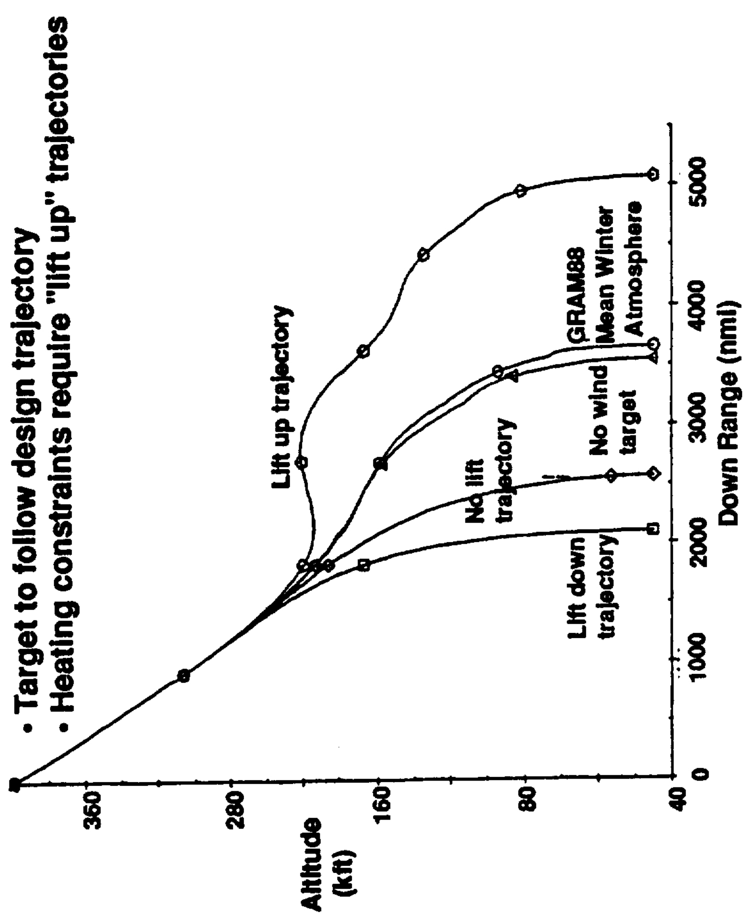


Figure 5.2.2-3 PLS Guidance Targeting Trajectories

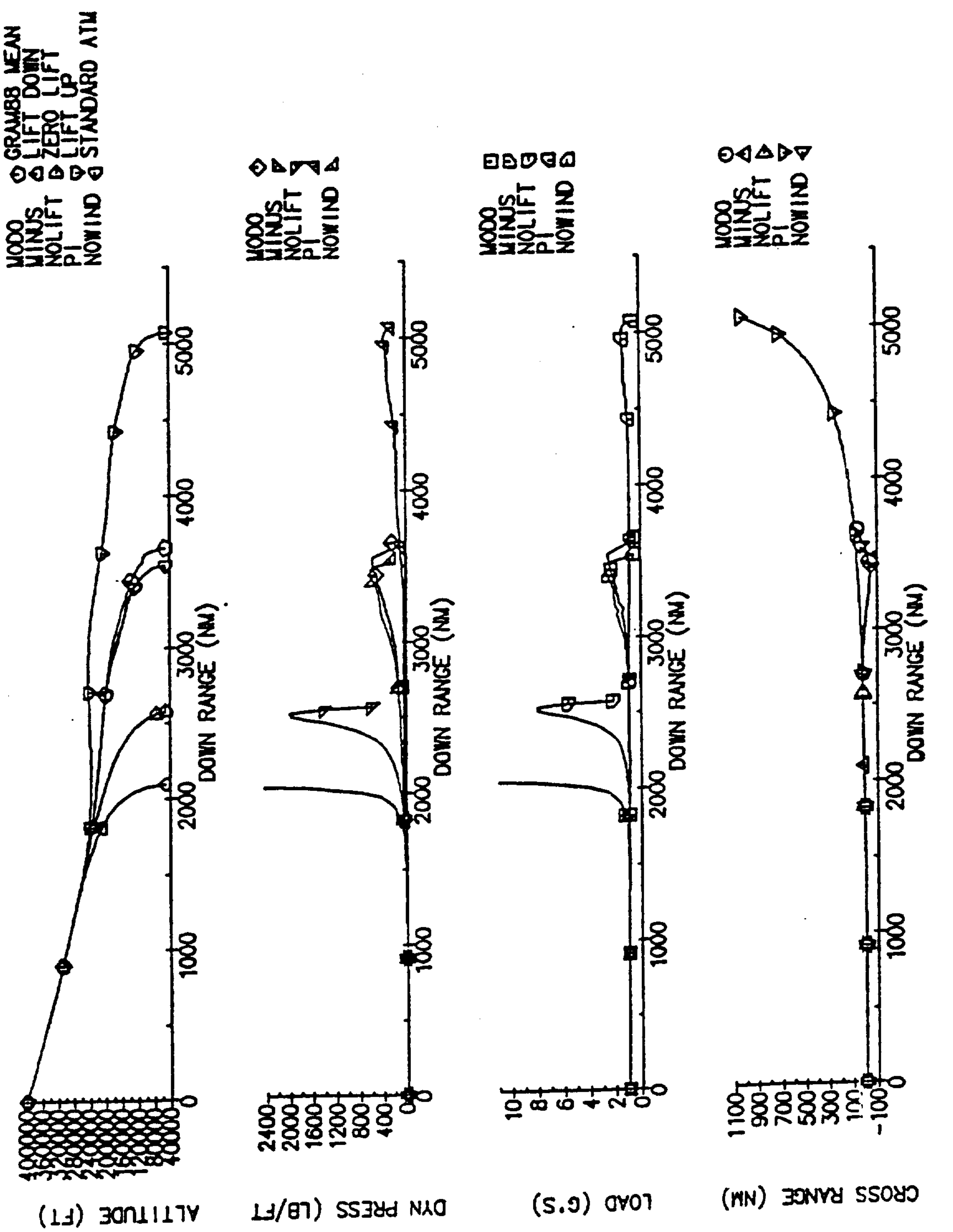


Figure 5.2.2-4 Trajectory Loading

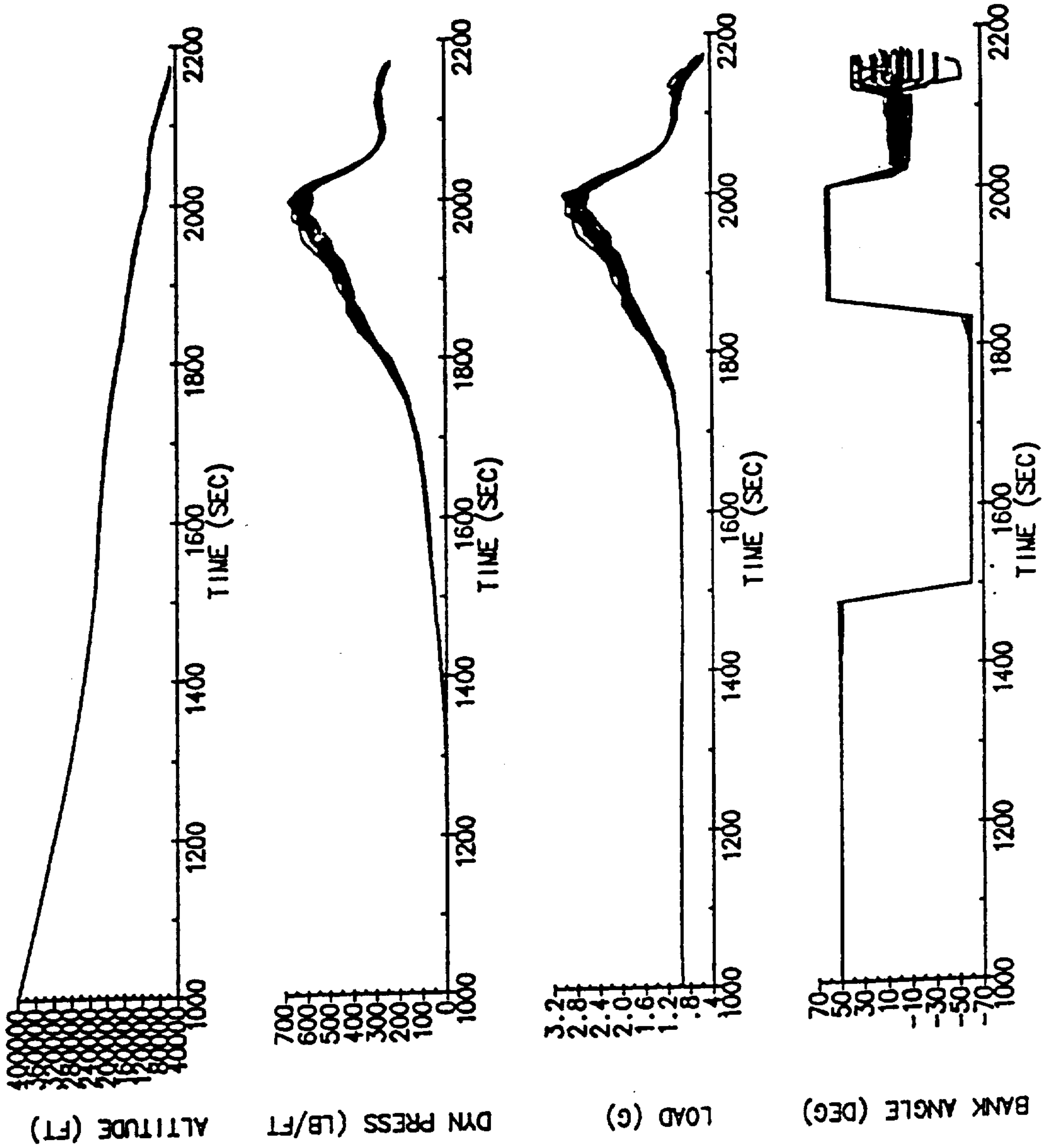


Figure 5.2.2-5 Guided Trajectories

5.2.3 Landing Surface

The type of landing area (water or solid ground, "prepared" vs. "unprepared") selected for nominal PLS missions will determine operational scenarios and subsystem selections. A fundamental design philosophy, however, is that the PLS will be able to withstand a survivable landing (of the personnel) on any surface medium; the vehicle does not necessarily have to be recoverable and/or reusable after landing on a surface other than the nominal design case.

Landing on water presents a set a design and operational challenges. Recovery system hardware can be simpler, and hence lighter than a land lander. Specifically, impact attenuation hardware may not be necessary for water impact. The thermal protection system and any exposed subsystems or access doors would require effective moisture sealants and/or significant cleaning/drying/resealing after exposure to the corrosive water environment (especially salt water immersion). Finally, the most significant impact of water landing is in the area of recovery operations. Recovery forces must operate at varying locations and extract the vehicle from a moving surface and transport the vehicle to a refurbishment site a significant distance away.

Landing on land could occur at a "prepared" site, such as a runway or flat field, or an "unprepared" site, which could cover anything from pasture to mountainous terrain. Landing at a specific location requires a more sophisticated guidance, navigation, and control scheme than landing at an unprepared site (or on water). Any land landing requires some form of impact attenuation and/or terminal deceleration enhancement to meet allowable shock loads.

In comparing land vs. water landing options, three important observations can be made. First, solving the hardware and operational problems associated with either landing mode is feasible and well within the technology availability constraints. Secondly, while the hardware weights associated with the differences in impact attenuation and landing precision as well as the cost "deltas" involved with water immersion protection were assessed, these comparisons were far overshadowed by the operational cost and safety differences associated with the landing scenario. Thirdly, the cost of a precision landing (to a prepared site) are small in comparison to the operational cost and crew safety benefits of returning to a specific location.

Based on these observations, it is recommended that the PLS should be designed to land at a specific prepared site (or one of a set of candidate sites). This is similar in concept to the landing scenario with the current shuttle Orbiter.

5.3 Utility Trades

Originally, it was proposed that the following trades be performed in this task:

Degree of Reusability

Modularity

Servicing Hardware.

It was quickly realized, however, that the options for these trades are highly configuration dependent, and that conclusions drawn for even the most generic POD may not hold true for a given configuration. For this reason, these trades were explored during design of the selected concept(s) (Task 2c - Section 9 of this report).

6 SELECTION OF THE PREFERRED CONCEPT

As seen in Section 3, the number of general geometric shape options for the "low L/D, no wings" PLS is large, not counting the infinite variations in angles and curvatures that are possible. While all these shapes could work, some are more desirable than others.

All the shapes explored in this category tend to be simple, axisymmetric designs with relatively high volumetric efficiencies. Preliminary weight analyses of five different shapes with the same payload (passengers) was performed. The results, as seen on Figure 6.0-1, show all the weights to be within a 10% band. These differences are probably within the level of uncertainty associated with calculations at this conceptual depth, and must be considered insignificant differences. Therefore, the traditional discriminator of weight (or costs which are based on weight) is probably not useful for determining the best PLS shape.

Instead, other less quantitative parameters must be used to sort though the shape options. The selected comparison criteria represent features that have been shown on past programs to be important, but are difficult to quantify in the absence of "hard" requirements or data. The following paragraphs describe these criteria, in no particular order or weighting.

Aerodynamic database - The amount of development time for a new aerodynamic vehicle is related to the test program that defines aerodynamic performance, aerothermal heating, and stability and control characteristics (see Figure 6.0-2). Novel shapes, or shapes that are difficult to model in a computer code will require more wind tunnel, subscale, and flight test and will thus add cost to the development program. In the case of the low L/D candidate shapes for PLS, most choices are geometrically similar to other past programs and are fairly simple to model for computational fluid dynamics codes.

Trim/center of gravity sensitivity - Some aerodynamic shapes are more stable or are easier to control. The relationship between the center of gravity (c.g.) and the center of pressure (c.p.), especially during hypersonic reentry is critical to flight safety, and also has a direct bearing on control system requirements. In some concepts, the design can accommodate a larger range of possible c.g. positions - important for mission flexibility and growth (refer to Figure 6.0-3).

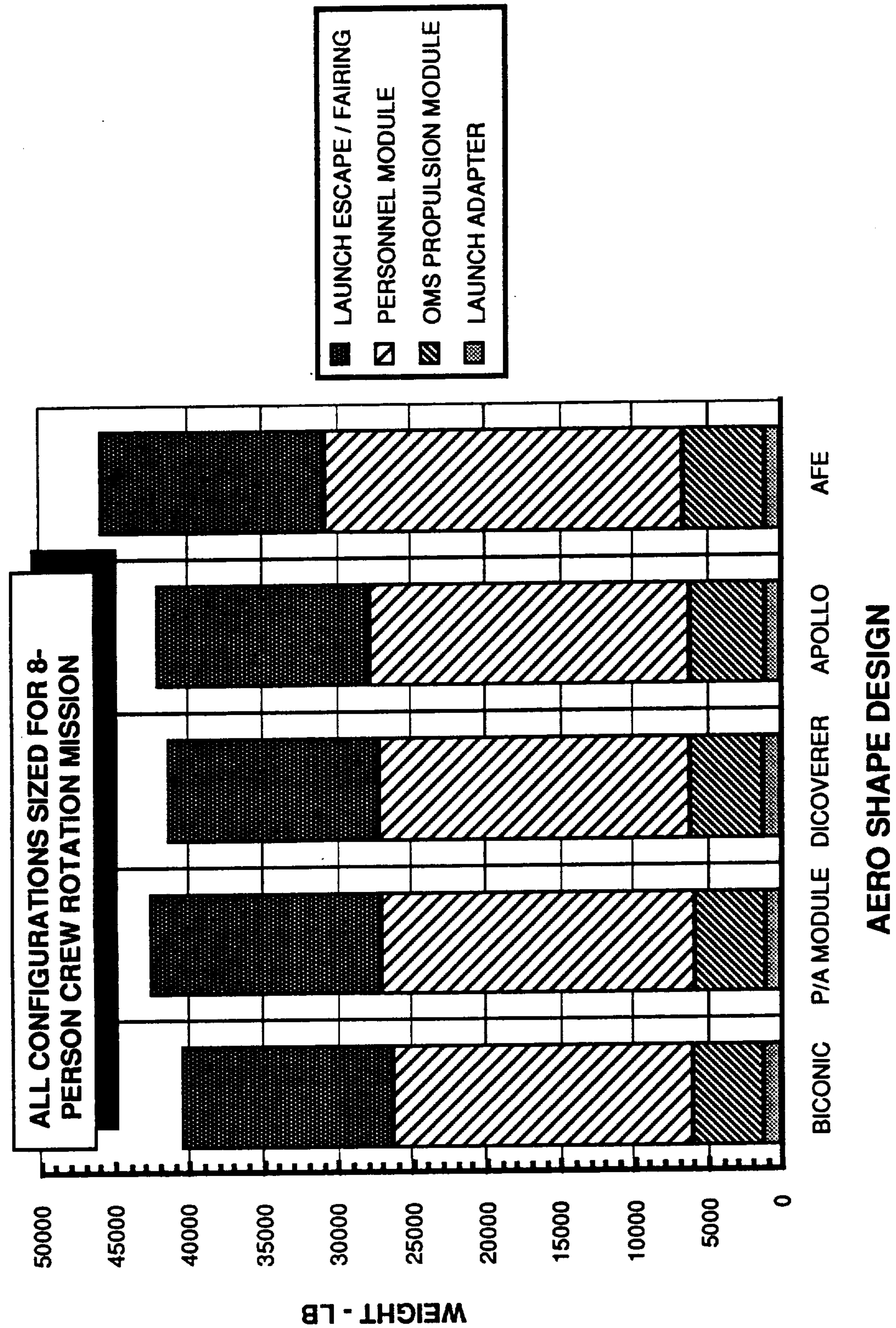


Figure 6.0-1 Mass Comparison od PLS Concepts

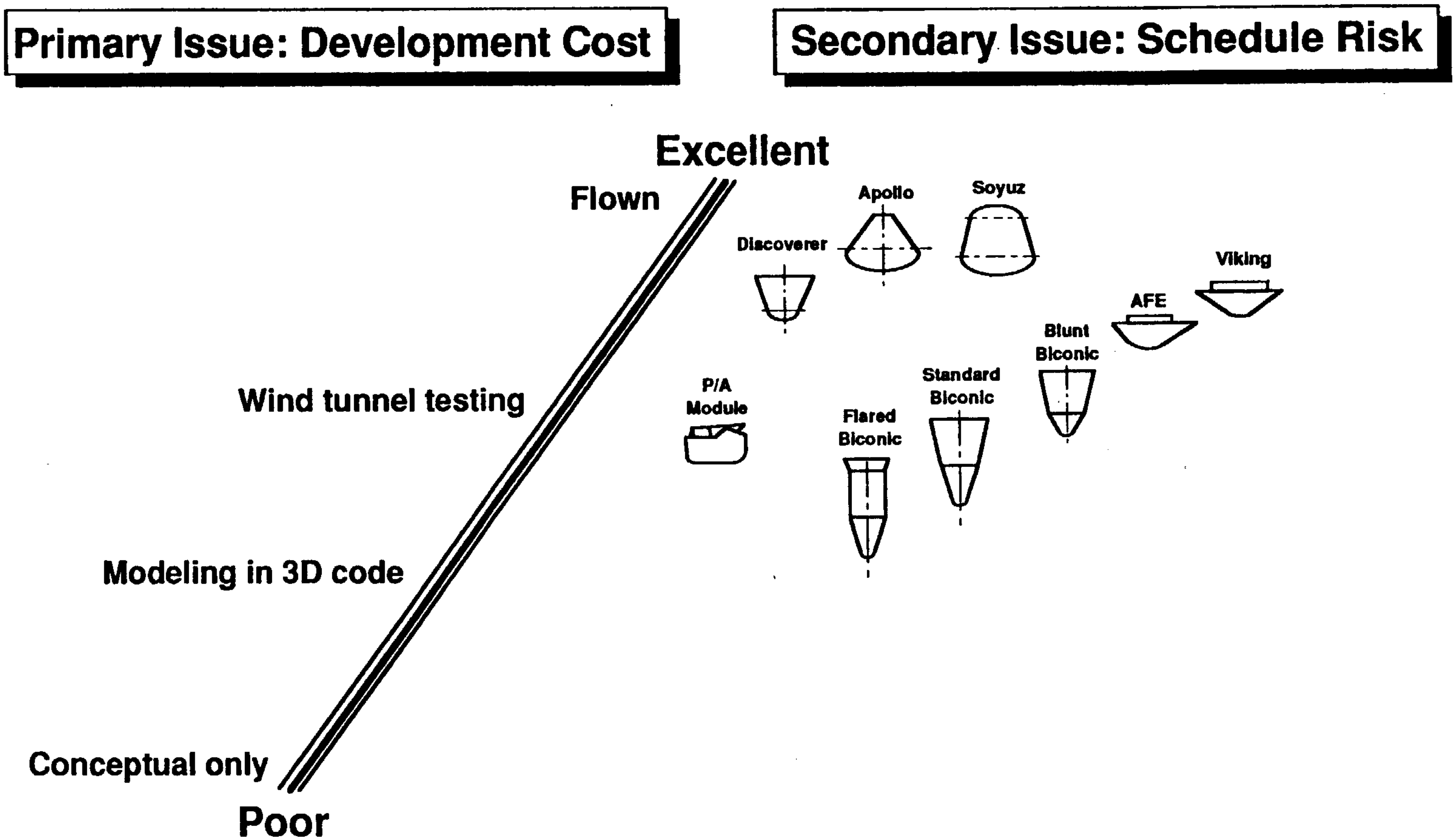


Figure 6.0-2. Aerodynamic Database Comparison

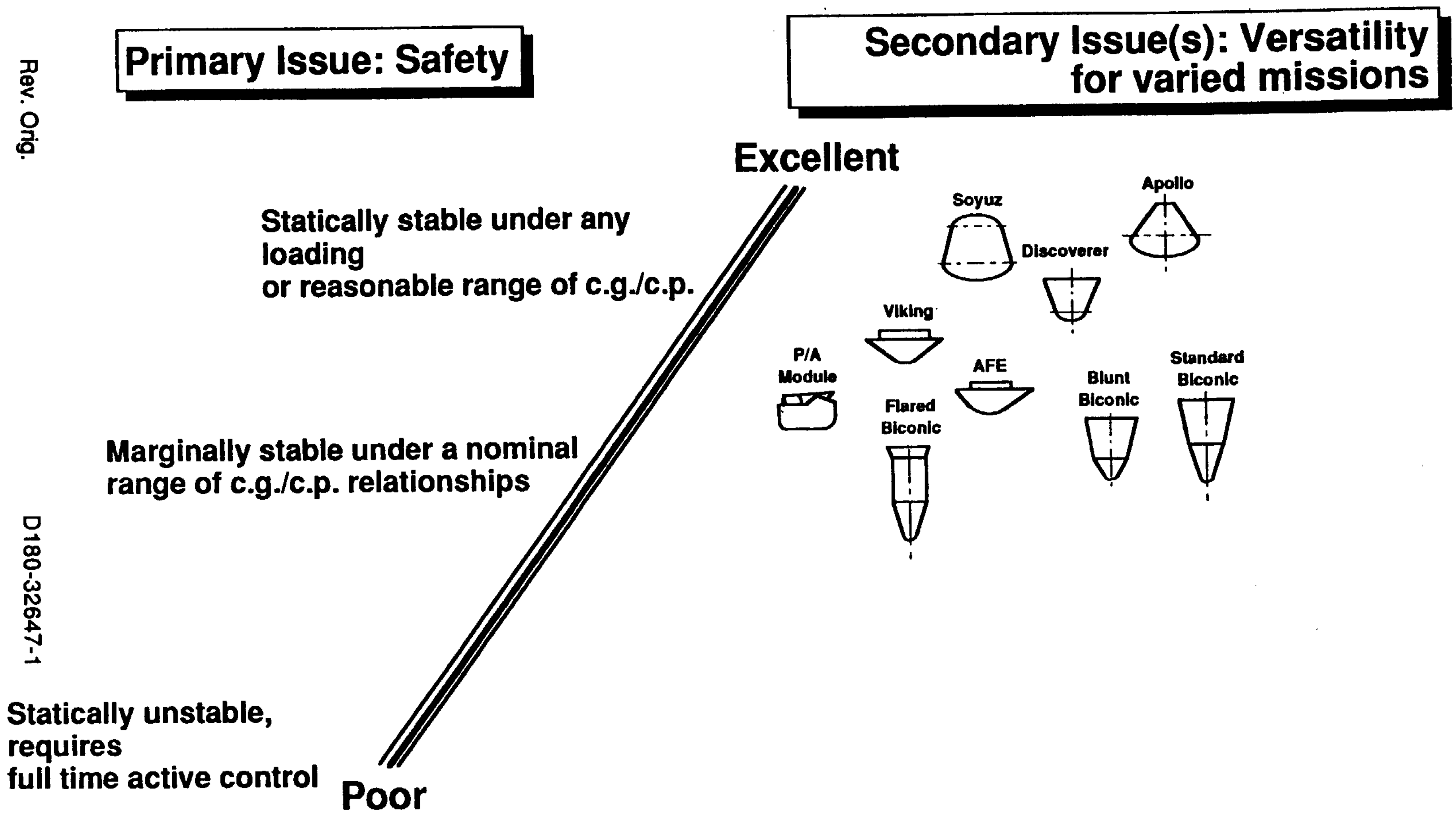


Figure 6.0-3. Trim/Center of Gravity Sensitivity Comparison

Launch vehicle integration - The interface between the PLS capsule and the launch vehicle should be as simple as possible both to enhance safety (clean separation) and to minimize the recurring costs associated with a fairing/interstage structure (Figure 6.0-4). Some concepts are very simple, others require extensive adapters.

Accessability - A key driver in ground processing timelines is the ability to readily and easily access any component that may require repair/refurbishment. While most of the accessability concerns are addressed by careful design and provisions for access cutouts, some shapes inherently lend themselves to easier servicing (see Figure 6.0-5). Concepts which have a high percentage of their surface area subjected to high temperatures complicate the access problem by requiring seals and special fasteners on some doors/hatches. Previous manned capsule servicing also tended to be limited by interference problems when technicians needing to be inside the vehicle's small volume to access subsystems tried to access those subsystems. Some concepts lend themselves to exterior access easier than others.

Transportability - The cost of ground operations includes equipment and personnel involved in moving the PLS from the recovery site to a refurbishment site to a launch vehicle integration site, etc (refer to Figure 6.0-6). The more modes of transportation available, the easier and less costly these operations will be. Of particular interest is the transport from the landing site to the refurbishment site. If the vehicle lands very near the refurb site, this is a small problem, but this severely restricts operational flexibility and perhaps overflight safety. If, on the other hand, the transport is a dedicated hardware item (such as the STS carrier 747 aircraft), the cost of transportation becomes significant. The best compromise would be to land at a site accessible by a non-dedicated, ideally unmodified transport. Although the weight and size of the shape options could be accommodated by conventional tractor-trailers or railroad car, height and width restrictions may limit routes. Air transport seems most likely, allowing for rapid, secure return of PLS hardware. The most likely candidates for this job would be an Air Force C-5 or C-17 transport. Weight of an empty PLS would easily be carried by a standard floor and hold-down mechanisms. The dimensional constraints, however, limit some shape options.

Manufacturability - At the conceptual level, it may be difficult to discern between shapes of unknown detail and materials. Some generalizations are appropriate, however. Separate pressure vessels and outer skins may require additional structural

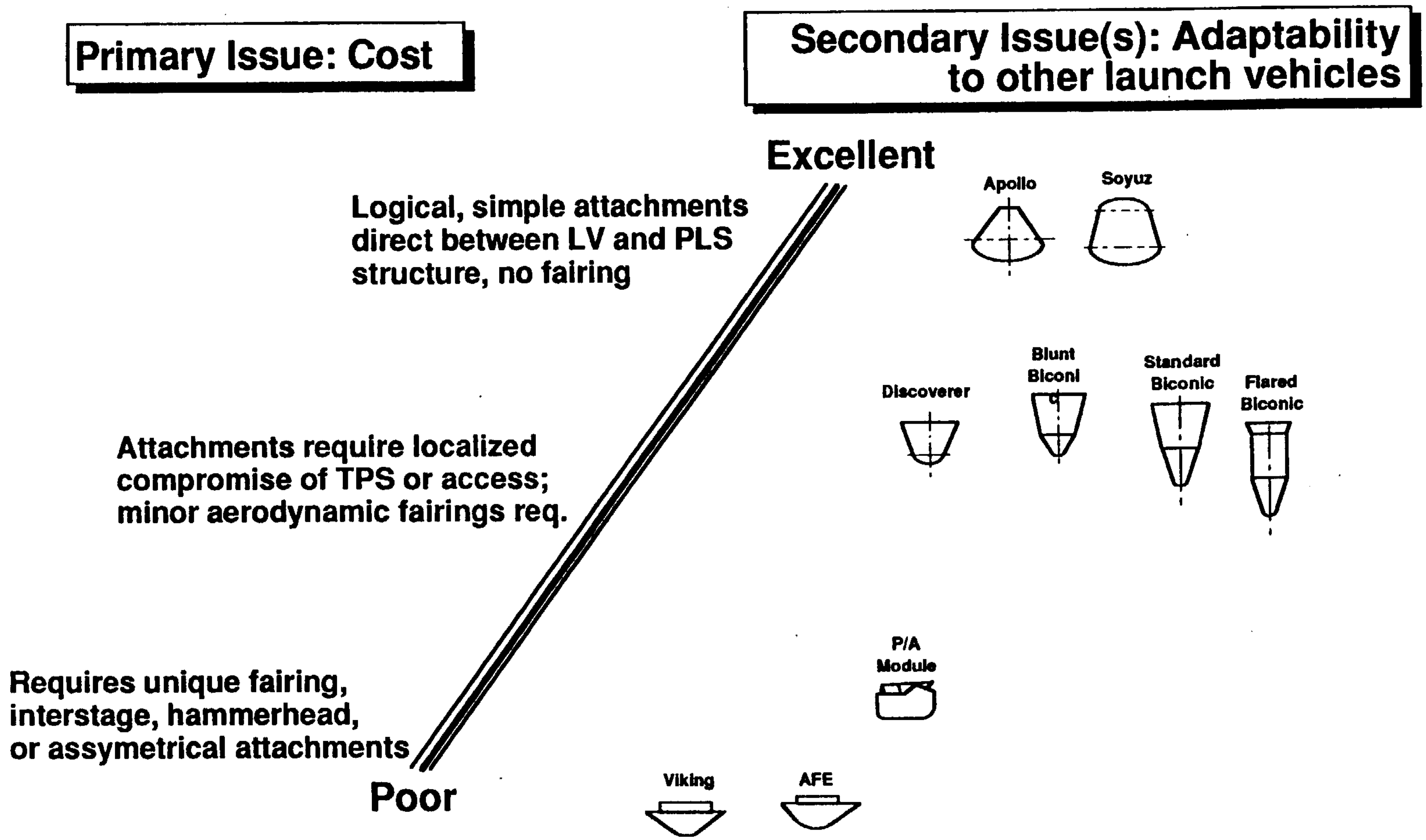


Figure 6.0-4 Launch Vehicle Integration Comparison

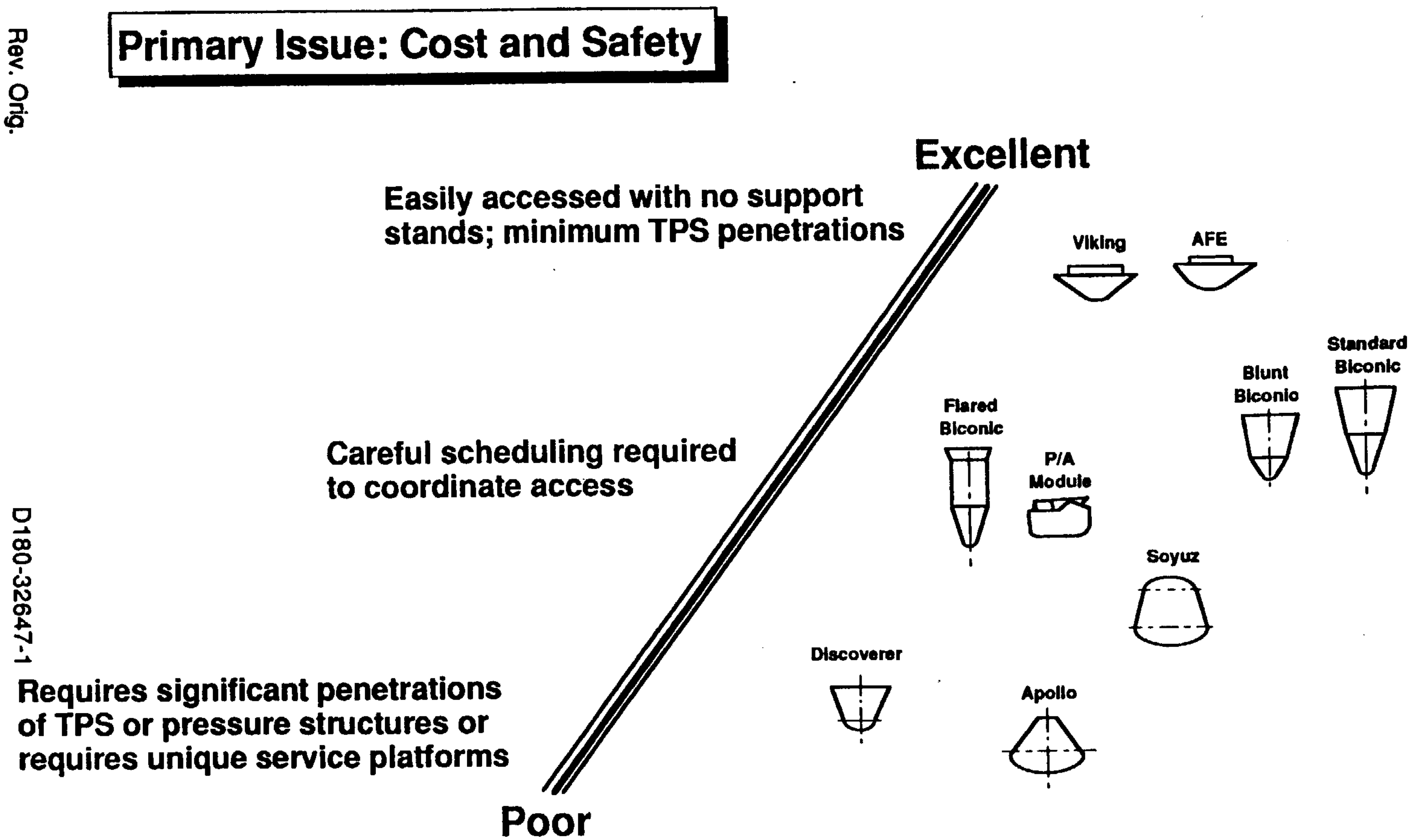


Figure 6.0-5 Accessability Comparison

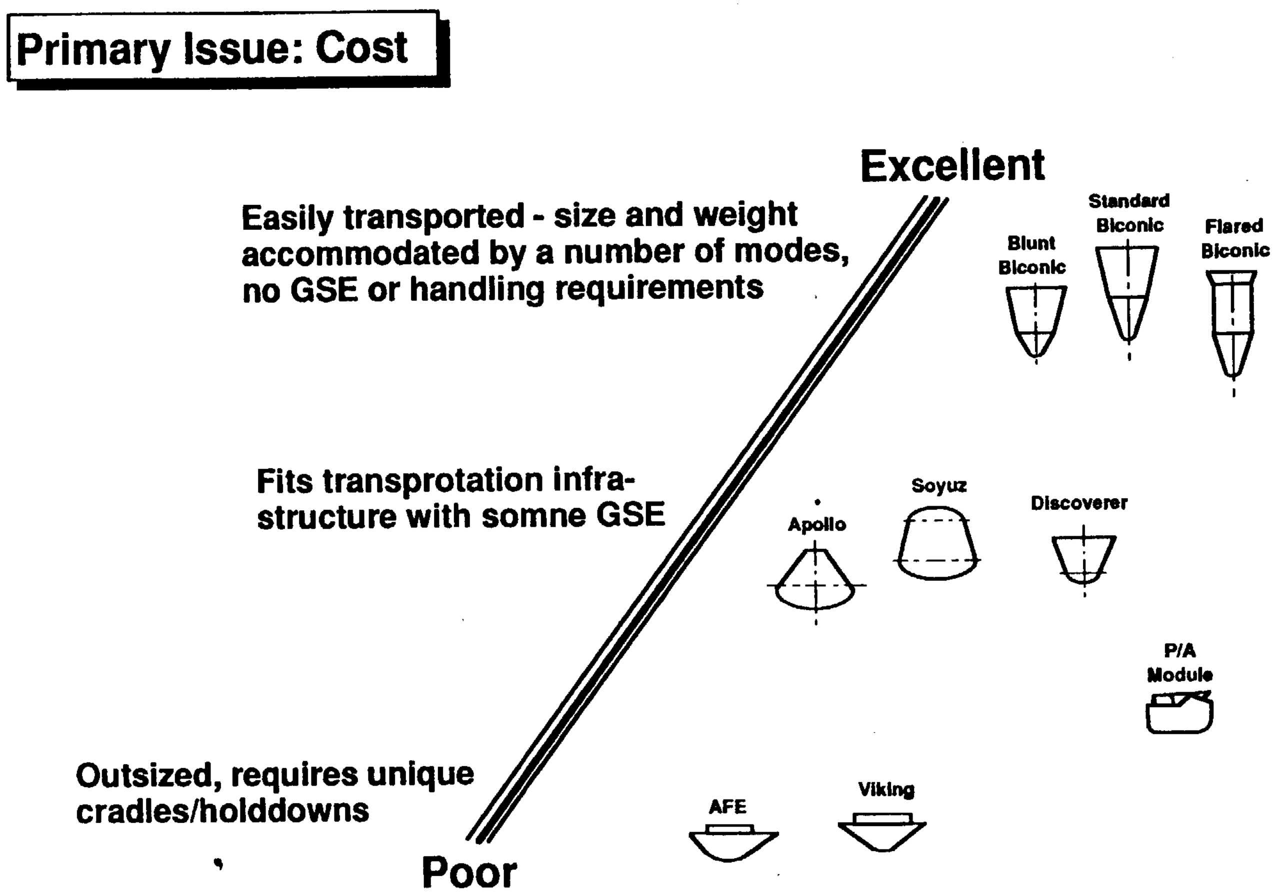


Figure 6.0-6 Transportability Comparison

parts. Small radii of curvature/sharp leading edges may imply more demanding tooling. Subassemblies that can be built up independently and joined at final assembly are usually easier to manage than one buildup (Figure 6.0-7).

Launch escape system integration - There are several options for the type of launch escape system installation on each concept. As in the launch vehicle integration considerations, some concepts will require more complex structural attachments and/or fairings than other concepts and will consequently be heavier and more costly (see Figure 6.0-8).

Water stability - Although the primary landing site for the PLS will be a dry land site, there may be emergency situations where the vehicle will land in the water. The impact loads on the water are dependent in part on the shape that contacts the surface over time. Using the analogy of the diver, a pointed shaped will slip into the water with a lower deceleration than a flat "bellyflop" impact. Figure 6.0-9 shows the difference for two types of shapes as they enter the water; water entry is discussed in more detail in Section 9.9.3 for the selected concept.. After impact, some shapes will be more stable in a float (a better boat) and will require less in the way of floatation devices or righting bags (see Figure 6.0-10). Seaworthiness is important in that an emergency landing may result in a lengthy wait before rescue.

Land stability - During a nominal land landing, uneven terrain and surface winds could cause the PLS to overturn, a safety issue and a potential source of damage to the vehicle. To avoid having the "landing gear" design become overly large or complicated, the shape should provide some inherent stability; usually, a low c.g. and large radii of curvature of the "down" side will help. Also, penetrations in heat shields for landing gear should be minimized (see Figure 6.0-11).

Obviously, there are many opinions on the merits of each shape and as to the relative importance of the above criteria. It was hoped that a concept could be found that did well in all the categories and poorly in none. Out of the range of shapes, a biconic shape with a flattened bottom was selected as the compromise that showed the most promise. Although a good case was made for several other concepts, it gradually became apparent that the biconic shape was an excellent starting point for the program.

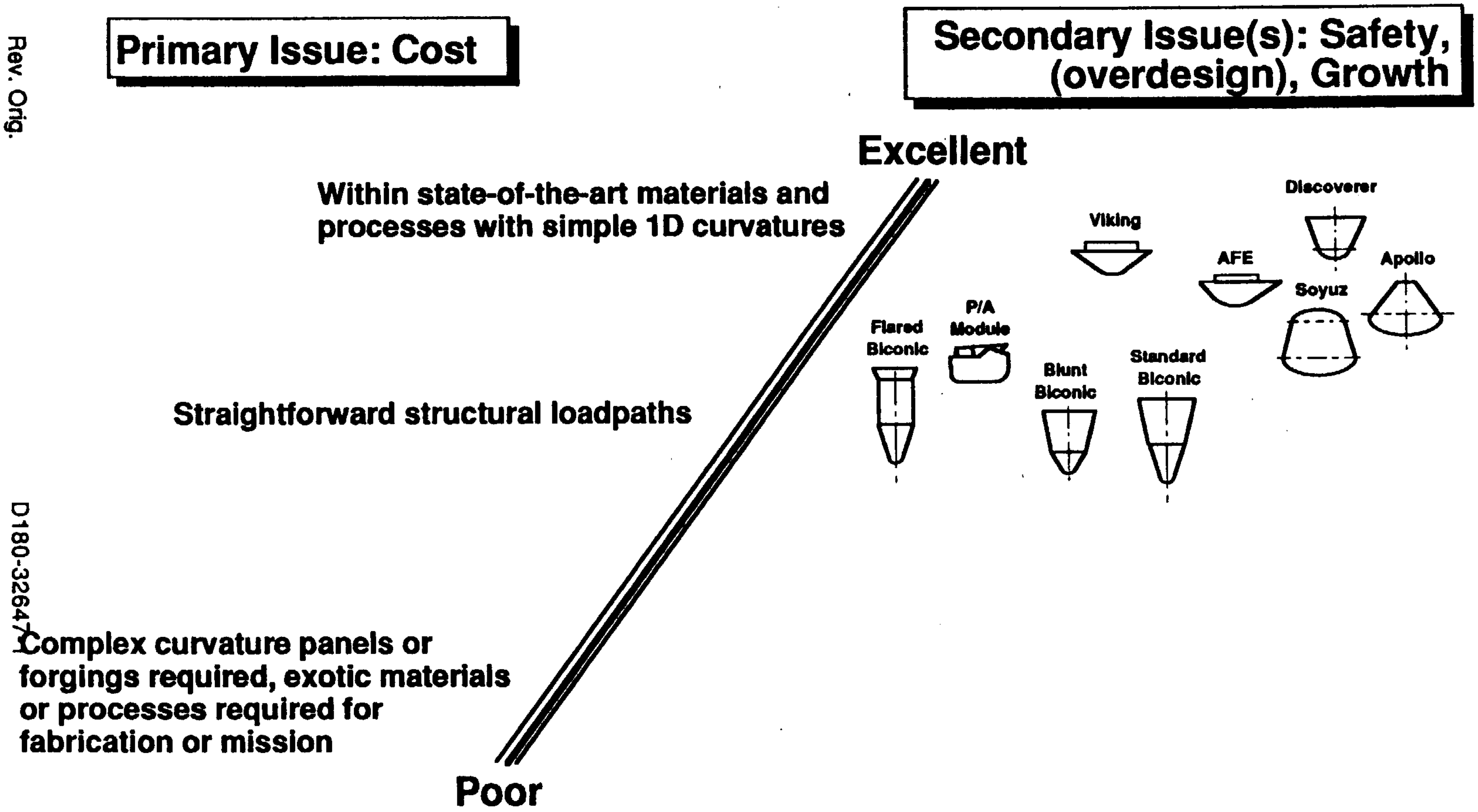


Figure 6.0-7 Manufacturability Comparison

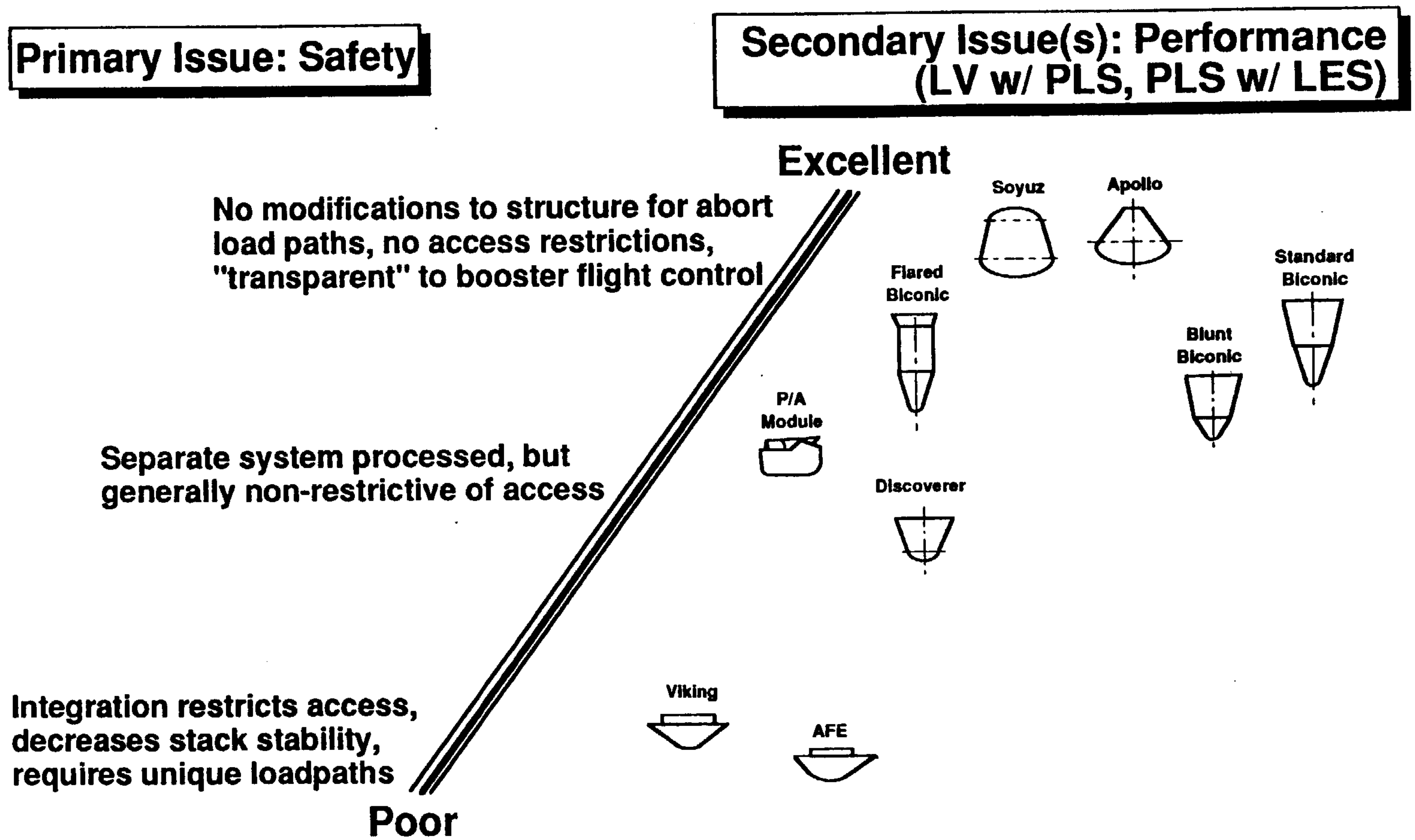
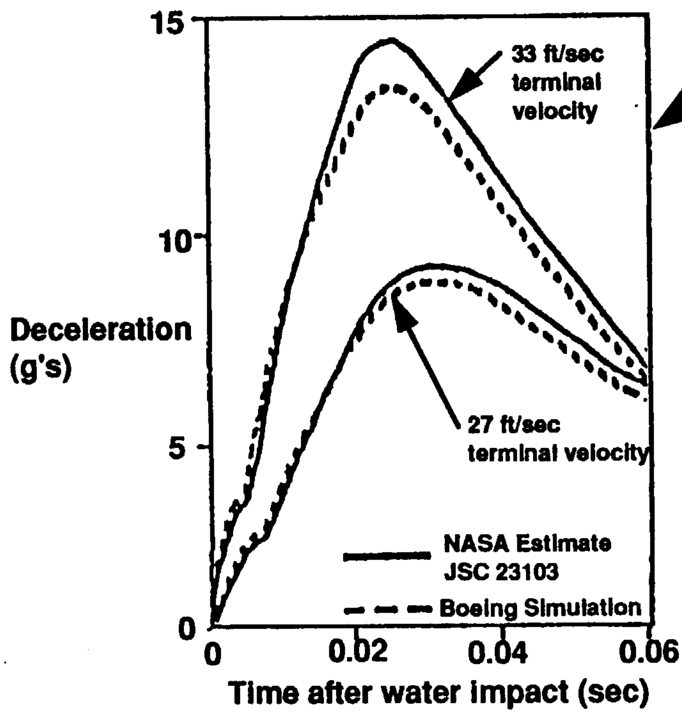
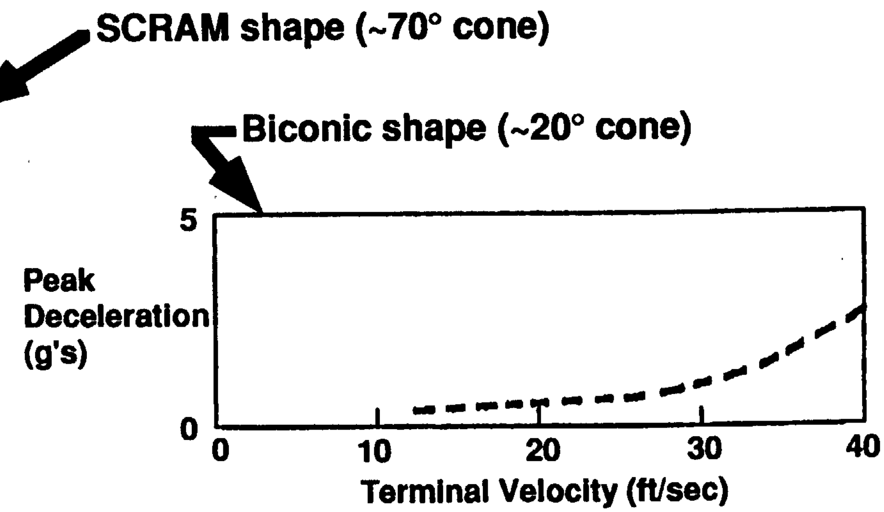


Figure 6.0-8 Launch Escape System Integration Comparison





- Deceleration forces determined from the time rate of change of momentum of the apparent mass. (Apparent mass is the sum of vehicle mass plus an added mass representing the displaced water.)

Figure 6.0-9 Water Entry Comparison

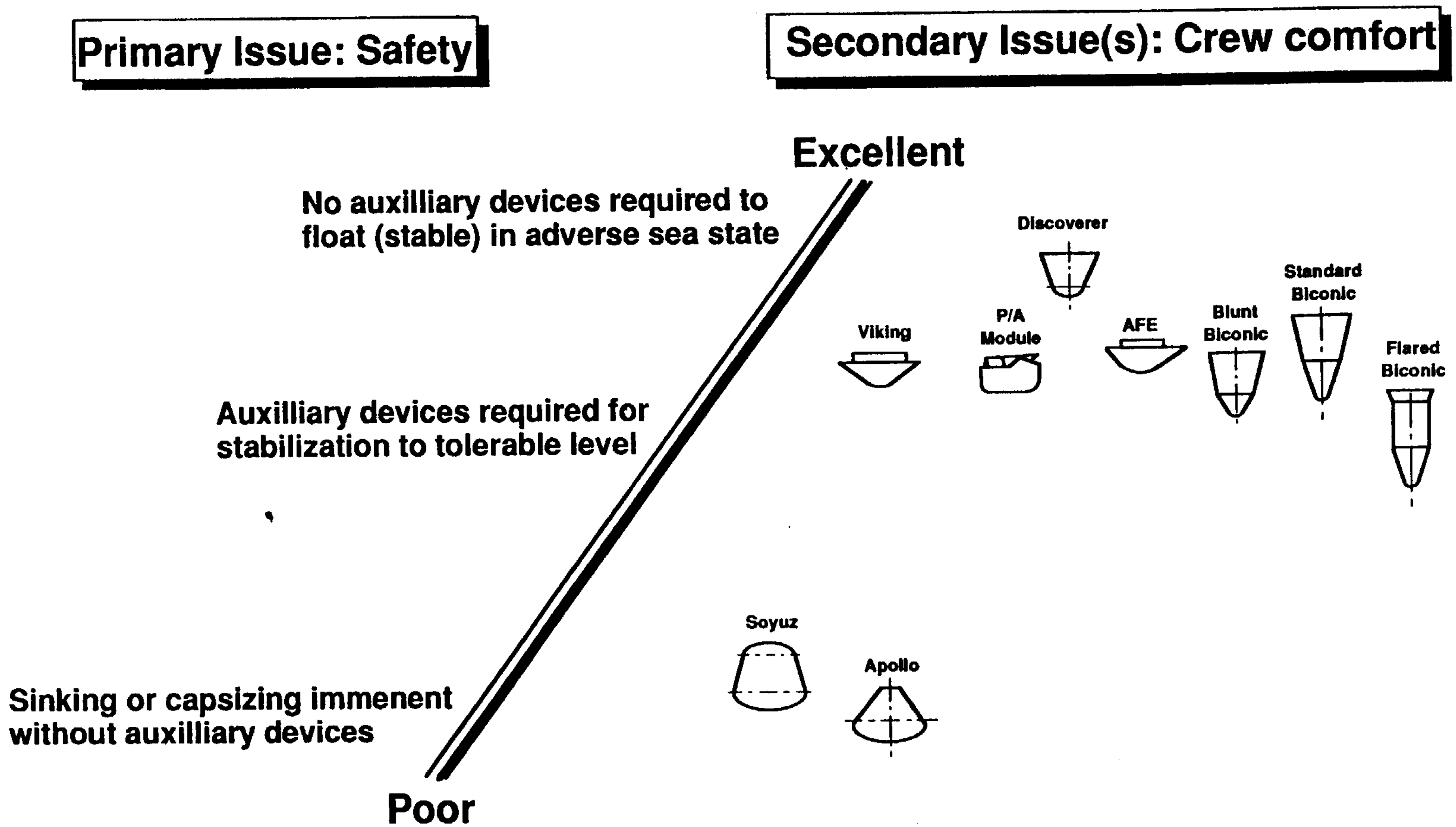


Figure 6.0-10 Water Stability Comparison

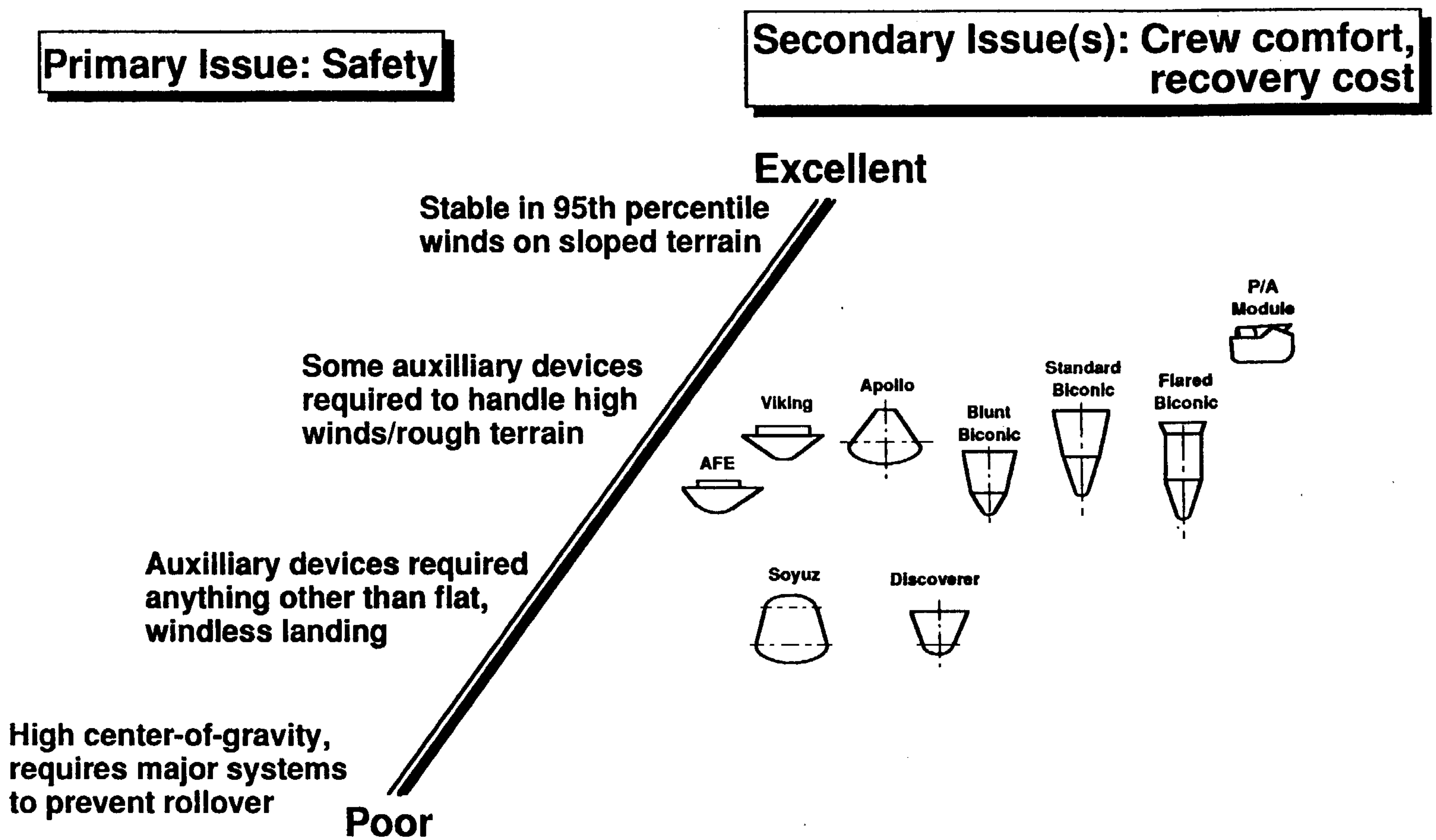


Figure 6.0-11 Land Stability Comparison

7 SAFETY CONSIDERATIONS

Manned space flight and operations necessarily involve a level of risk that must be accepted by flight and ground personnel. One of the primary reasons for developing a new manned launch system is to significantly reduce that accepted risk to the lowest possible level, perhaps approaching the level of commercial airline transportation. System safety discipline has been applied throughout the PLS concept definition to ensure that all phases of the PLS mission can be performed with minimum risk to people or property.

There are established criteria within the aerospace community which characterize events that place people and property at risk. *Catastrophic events* are those that could result in disabling or fatal injuries to people and/or the destruction of the PLS vehicle or other property. *Critical events* are those that could result in:

- non-disabling injuries to crew or passengers
- damage to the PLS vehicle or other property
- use of contingency or emergency procedures to save the mission
- mission degradation.

The approach used during the PLS concept definition was to reduce the probability of event occurrence through the use of conservative design, fault tolerance (a minimum of two fault tolerance for catastrophic events and one fault tolerance for critical events), and mitigation of event effects should the event occur.

7.1 Safety Process

System safety has been a prime consideration during all phases of the PLS concept definition. Specific subsystem selections, operational procedures, and mission planning all incorporate a systematic process for identifying undesired events and developing strategies for their mitigation and/or control. Figure 7.1-1 illustrates this process.

The process begins with a thorough understanding of the missions, the hardware elements, the operating environment and rules for the PLS (or subsystem). A list of potential hazardous *events* are identified. After identification, an evaluation is conducted to ascertain the causes and effects of hazardous events and to try to

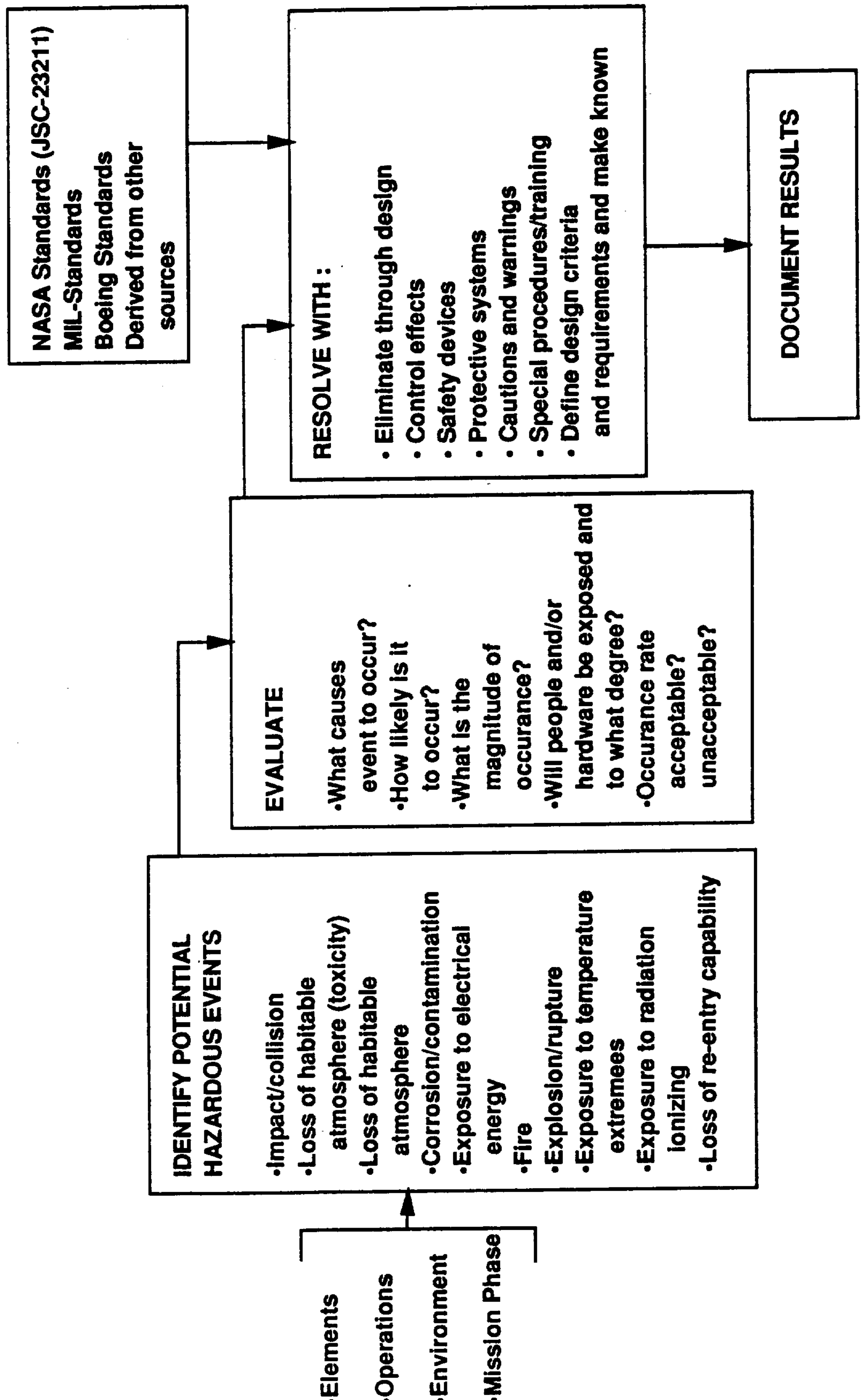


Figure 7.1-1 Generic Safety Process

determine whether the risk rate/magnitude is acceptable. Using standards developed for a variety of aerospace vehicles, unacceptable hazardous situations are resolved through design, additional features/equipment, and specialized procedures/training. These resolutions become part of the set of design and operational requirements for the PLS. An example of this process as it was used to define requirements for a launch escape system can be found in section 10.

7.2 Design Features

A key element for enhancing system safety is designing safety in from the outset. In addition, some specialized equipment may be included for the sole purpose of mitigating the effects of hazardous event occurrence.

The selection and design of the PLS systems and subsystems consider safety as a criteria. Hardware includes large margins of safety in it's design, or "over design", that enables a given component to operate without failure in an environment and/or loading condition in excess of the maximum anticipated case. Manned systems typically require higher margins than unmanned systems, which usually results in some system performance/cost degradation due to weight increases. There is a direct relationship between successful aerospace systems (in terms of safety record) and the degree of over design used. The PLS should exhibit margins in the range of commercial airline transports, not necessarily the same as traditional spacecraft, as they represent a proven compromise between safety and performance. Specific subsystem requirements, such as "leak before burst" criteria for tankage are also used to reduce the prescence catastrophic failure mechanisms.

The system strategy of redundancy and high reliability is also a direct contributor to overall system safety. Beyond some point, continuing increases in component reliability starts to cause exponential increases in cost, and the system becomes unaffordable. Similarly, it is known that adding redundancy (extra "strings") to a system decreases overall system reliability and adds to system weight, cost, and complexity. The philosophy for PLS critical systems will generally be fail-op, fail-op, fail-safe (abort); in other words, the system will be able to sustain two failures before emergency or abort procedures are begun.

System location and material selection also have influences on overall system safety. Specifically, locating tankage which stores fluids under pressure in a place that is

external to the crew's pressure vessel will significantly reduce the hazards from toxicity and shrapnel associated with a tank leak/rupture. Multiple crew ingress/egress hatches provide for alternate escape routes if one is blocked or jammed. The seating layout of the PLS should also reflect emergency egress considerations. For example, the three "rows" of seats as opposed to a long slender cab of say, five rows, provides a closer proximity to the exit without excess numbers of ladders, ordered folding of seats, etc. Material selection will determine the toxicity emergencies that could occur. Some materials can be eliminated outright, such as the propellant selection discussed in Section 9.3, others can be contained/isolated. Other toxins are byproducts of fire and will set filtration requirements for the environmental control system. Table 7.2-1 lists the probable range of toxins for a PLS and the approach to mitigating their effects.

Additionally, the design must account for the radiation and micrometeroid environment that the PLS will experience. Current construction techniques (aluminum airframes) seem sufficient for the low Earth orbit missions that comprise the bulk of the PLS mission model. Evolutionary missions for the PLS, such as a manned cab for the Lunar missions of the future, would require additional shielding. This analysis is complex and would require more detail than is available at this conceptual level of study.

There are some features of the PLS design which are included for the sole purpose of enhancing safety. This equipment would include floatation provisions/life rafts for a water landing, survival equipment, fire detection and suppression equipment, emergency lighting and a Launch Escape System.

7.3 Ground Operations

In examining the total system safety, consideration must also be given to the safety of the ground support personnel and facilities during vehicle refurbishment and maintenance. The safety requirements applied to these operations can have significant impact on performance time and operating costs.

Traditionally, one of the largest issue in ground operations safety has been the handling of hazardous fluids. Specialized facilities, equipment, and scheduling are often required. Within the subsystem trades (particularly propellant selection), the operations impacts of a given fluid selection was heavily weighted and was the largest factor in deciding which propellants to use. The relatively small quantities required

Table 7.2-1. Toxic Hazards

Substance	Hazard	Prominent Toxicological Effect	STS Applicaton:	Mechanism of Hazard	Present on PLS?	Risk Minimization Strategy
NH_3	T	Respiratory tract irritation	TC	L,M	Y	Containment, Location
0_2 (GOX and LOX)	CFE	Burns	ECLSS, FC	L,R	Y	Containment, Location
Fluorinated hydrocarbons (Halon, Freon)	TA	Shortness of breath, cardiac arrhythmia	TC,CI,FS	L,TD	Y	Containment, Restrict Usage
Chlorinated hydrocarbons (dichloroethane, trichloroethylene)	T	CNS depression, cardiac arrhythamia, liver toxicity	CI	TD,O	(TBD)	Careful examination of cleaning
Aromatic hydrocarbons (Benzene, toluene, etc)	T	CNS depression, dizziness	CI	TD,O	(TBD)	procedures/materials and selection of non-matellic materials/substances
Alcohols (ethanol, isopropanol, etc.)	T	CNS depression, (intoxica-tion), eye/respiratory irritant	CI	TD,O	(TBD)	
Aliphatic hydrocarbons (decane, butene, cyclohexane)	T	CNS depression		TD,O	(TBD)	
Aldehydes and ketones (methyethyl ketone, acetone, etc.)	TF	Eye, respiratory tract irritation	CI	TD,O	(TBD)	
He	A	Asphyxia	P	L,R	Y	Containment, Location
Hydrazine	T	Irritant/burns, CNS disruption	P	L	(TBD)	If trades result in these
MMH	T	Irritant/burns, CNS disruption	P	L	(TBD)	selections: containment, location
NTO	T	Burns, edema	P	L	(TBD)	
H_2 (LH and GH)	CFEA	Burns, asphyxia	FC	L,R	Y	Containment, Location
N_2	A	Asphyxia		L,R	Y	Monitoring, Containment
CO_2	TA	Asphyxia, cyanosis		M,TD	Y	Removal (LiOH)
CO	TA	Asphyxia, cyanosis		M,TD	Y	Removal
CH_4	TFA	Asphyxia		M	Y	Removal
Hg	T	Respiratory tract irritation	B	L	N	Eliminate by design
HF	T	Respiratory tract irritation		TD	Y	Removal
Cd	T	Headache, liver/kidney damage	B	L	(TBD)	Containment, Eliminate
Dust, lint, miscellaneous biological material	T	Infection, allergy, influenza		M	Y	Removal

Key:
T Toxicity (inhalation or skin contact)
C Cold contact
F Fire
E Explosion - secondary damage
A Asphyxiant

B Batteries
TC Thermal Control
FC Fuel Cells.
ECLSS Environmental Control & Life Support System

CI Cleaning
FS Fire Suppression
P Propellants/Pressurant
L Leak

R Rupture/Puncture (High Pressure)
M Metabolic By-product
O Outgassed
TD Thermodegradation or Result of Fire

and "external" tank location should further reduce processing impacts. The small physical size of the vehicle and its components should also reduce hazards due to handling mishaps as compared to a Shuttle Orbiter sized vehicle.

7.4 Orbital Operations

While on orbit, certain operations will have a greater safety influence on the PLS design than others. For example rendezvous and docking with other spacecraft introduces a set of scenarios that could lead to hazardous events. In the case of the SSF or other manned vehicles, the PLS itself, could be considered a potential hazard to those vehicles.

Thorough consideration of operational procedures and contingencies are required to minimize the on-orbit hazards of two co-located vehicles. The PLS design must include features in addition to the normal navigation and control that will provide for other contingencies. For example, the docking mechanism or the manipulator arm that is in contact with the other spacecraft will be jettisonable to ensure a clean separation in the event of a malfunction. Inclusion of a cold gas system and appropriate jet selection logic will ensure that the attitude control emissions will not impinge directly on the other spacecraft. Windows are included in the PLS which provide for a visual, independent assessment of interferences or potential problems.

7.5 Emergency Situations

There are, unfortunately, many emergences that could befall the PLS during it's missions. Some emergencies require immediate response to save the vehicle/crew, others are more benign but still necessitate some contingency actions.

At the conceptual level, it is impossible to do a complete Failure Modes and Effects Analysis (FMEA) such as would be generated for a more specific design. The FMEA would identify in some detail the cause and effect of failures and would identify those failures that could lead to emergency situations. At the conceptual level, it is possible, though, to examine the general types of emergencies by flight phase to drive out design requirements.

The most spectacular category of emergency involves an explosion. Usually caused by a propellant detonation, the time available for countering actions is very short, usually less than 5 seconds. The problem is significant enough on ascent to require a

launch escape system (LES) and is discussed in more detail in Section 10. Appropriate use of sensors for maximizing warning time would greatly improve the odds of surviving an explosion. This will, however, require an interface (data link) between the PLS vehicle and the launch vehicle (additional cost and complexity).

Another category of emergency involves fire. Flammable materials will be present to some degree and the location and intensity of any combustion will determine the severity of the emergency. Obviously, reducing the number of flammable substances and locating them away from heat/spark sources is desirable. Typical times for responding to a fire range from 5 seconds to 20 seconds, depending on detection sensors. Fire suppression equipment is included in the PLS design.

Loss of control could result in an emergency within a second or up to 10 minutes later. Of course, there are many variables, such as attitude, moments of inertia, and dynamic pressure, which will influence the required response time. A control emergency would typically be caused by a control system failure, a reaction control system failure, loss of thrust, collision, structural failure, or an actuator or valve failure.

Emergencies can arise when the vehicle is damaged, as in a micrometeor strike or a collision. These emergences generally lead to one of a number of other emergencies: control loss, pressure loss, or explosion.

Graceful system degradations can take hours to develop, but are just as serious an emergency as more spectacular events. Instrument failures, loss of power, or loss of thrust are examples of situations requiring contingencies or work-arounds to salvage the crew/vehicle.

Finally, a category of emergencies exist involving a hazardous environment for the crew. Failures in the ECLSS, loss of pressure integrity, and toxic gases (usually resultant from fires) could require fast response times (on the order of seconds).

Table 7.5-1 depicts, by flight phase, the time that would typically be available to respond to an emergency situation for several key subsystem elements. Note the potentially very short times related to ascent phase explosions. Section 10 will address this problem in particular by defining a launch escape system.

Table 7.5-1 Response Times to Emergency Situations

Hazard Condition \ Flight Phases	Pre-Launch ~4h	Launch/Initial ascent ~2m	Hypersonic ascent ~6m	Orbital flight 0 to 66h	Re-entry ~45m	Landing/ Post Landing ~1h
Propulsion Failure: Booster Propulsion OMS/RCS Propulsion Fuel lines, valves, pumps, tanks	<1s to 2m <1s to 30s	<1s to 30s <1s to 30s	15s to 1m 1m to 6m <1s to 3	5m to 66h to 66h	5s to 1m 5s to 10s	
TPS Failure				? to 66h	5s to 10s	
ECLSS Failure Pressurization Oxygen supply Contamination	? to 4h 5s to 30m	? to 5m ? to 2m 5s to 2m	? to 10s ? to 6m 5s to 6m	? to 10s ? to 4h 5s to 30m	? to 10s ? to 45m 5s to 30m	5s to 30m
Aerodynamic devices					1s to 1m	
Collision				10s to 66h		
Chemical Explosion	<1s to 30s	<1s to 30s	<1s to 30s	10s to 12h	10s to 1m	<1s to 30s
Cabin Fire	5s to 30s	5s to 30s	5s to 30s	5s to 30s	5s to 30s	5s to 30s

s = second m = minute h = hour

8 MASS PROPERTIES ESTIMATION

Mass estimation is not a distinct "step" in the design process, but is performed as an integral part of the design process. In general, mass properties analyses were used in the selection process to support the trade study and configuration decisions. In this section, only the final weights associated with the preferred concept are shown. A similar analysis was performed for each subsystem trade study (see Section 9) to document the mass properties of the trade study options.

8.1 Methodology

Weight estimation of the PLS followed the process shown in Table 8.1-1. Allowances for installation and unknowns are added to identified equipment weights, and then a weight growth margin is added to the combined dry mass to account for future design changes. Elaboration of some of the terms are found in the following paragraphs.

As-Designed Weight

At the conceptual design level, most identified weights are estimated from preliminary sketches and layouts, with attention paid to identifying subsystem components and equipment to the level required to develop preliminary cost estimates.

Structural unit weights are based on other similar designs, or in many cases estimated as minimum gauge. Thermal protection unit weights are based on requirements developed by thermodynamic analysis of reentry conditions. Allowances of 5 to 20 percent are added to structures and TPS for tolerances, fasteners, and assembly depending on complexity or on similar aerospace assemblies. Propulsion, electrical power, avionics, ECLSS, and auxiliary system component weights are based on existing or similar designs, with allowances of 10 to 25 percent added for support and installation of equipment.

Weight Growth Allowance

During this program phase, a weight growth margin of 15% of vehicle dry weight is added to the total dry weight to allow for design changes required to meet delivery date specifications. As the vehicle becomes more defined and as actual weights are incorporated, this weight growth margin will probably be depleted. Based on the

Table 8.1-1 Weight Estimation Methodology

1	Identified Weight	The minimum weight estimated or calculated from equipment lists, system layouts, preliminary sketches, etc. This accounts for all major subsystems and components to the level required for accurate cost analysis.
2	Contingencies, Allowances	Weight included to account for secondary design elements, assembly, or manufacturing tolerances not specifically identified in the design. The amount depends on the component or subsystem design maturity.
	AS-DESIGNED WEIGHT	
3	Weight Growth Margin	Weight allotted for effects of design changes required to meet specifications applicable at time of delivery - current margin is 15% of total dry weight, which is typical for a vehicle concept definition phase.
	PROJECTED WEIGHT	

history of past programs, a 15% weight growth allowance indicates approximately a 70% probability of staying within the projected dry weight.

8.2 Selected Concept Mass Properties

PLS mass summaries for the crew rotation (DRM 1) and manned satellite servicing (DRM 5) missions are given in Figures 8.2-1 and 8.2-2 respectively. The masses are shown by subsystem for the major flight elements, including: the crew module; OMS propulsion module; launch escape system; and the aerodynamic fairing. As mentioned previously, all dry weights include a weight growth margin of fifteen percent to account for possible design changes required to meet the necessary specifications at the time of delivery.

For the servicing mission, the service module and remote manipulator system masses are included in the crew module subsystem masses. The service module airlock is jettisoned prior to crew module reentry, but the remote manipulators are retained for re-use.

Tables 8.2-1 and 8.2-2 show propulsion system characteristics for the crew rotation and satellite service missions respectively. These characteristics include: typical consumables usage; summary and sequential fluid inventories and; sequential weights. The OMS propellant load includes a 10% reserve, the RCS includes a 20% reserve, and the proximity operations system includes enough propellant for redundant rendezvous operations in addition to a 20% reserve. The crew rotation mission requires consumables for 13.5 person-days, propellants for a ΔV requirement of 1145 ft/s, power reactants for 416 kW-hr, and enough O_2 and N_2 for a 2%/day cabin leakage and one contingency cabin repressurization. The satellite servicing mission requires consumables for 28 person-days, propellants for a ΔV of 1483 ft/s, power reactants for 786 kW-hr, and enough O_2 and N_2 for a 2%/day cabin leakage, one contingency cabin repressurization, and two airlock repressurizations to support EVA.

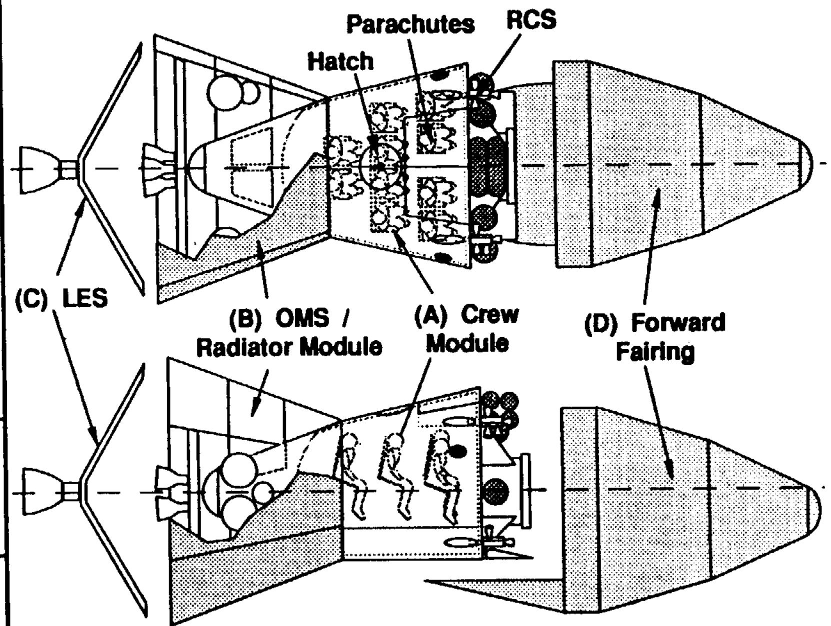
A detailed weight and balance statement with size and material data is given in Table 8.2-3 for the crew rotation mission and satellite servicing mission. Major differences between the mission configurations are as follows:

Structures - The docking adapter is replaced with an airlock interface ring for the service mission. Total weight change is -293 lbm.

Crew / Passengers: 2 / 8 — Mission Duration : 72 Hour

Functional System	A	B	C	D
1. Structure	5116	1312	260	1747
2. Protection	1220	71		239
3. Propulsion	972	1066	2058	
4. Power - Electrical	2157	188	40	
5. Control	121			
6. Avionics	1637			
7. Environment	1406	795		
8. Other - Personnel Provisions	1535			
Other - Landing, Aux Systems	2522	150	32	362
9. Weight Growth Margin	2503	537	358	352
Dry Mass	**19189**	**4119**	**2748**	**2700**
10. Non-Cargo (See Note 1)	3583	844		
11. Cargo	0	0		
Inert Mass	**22772**	**4963**	**2748**	**2700**
12. Non-Propellant Consumables	873			
13. Propellant - Nominal	563	2949		
Gross Mass	**24208**	**7912**	**2748**	**2700**
	32120		5448	
Total Mass	**37568**			

Configuration: Flattened Biconic



Notes:

All Mass In Pounds

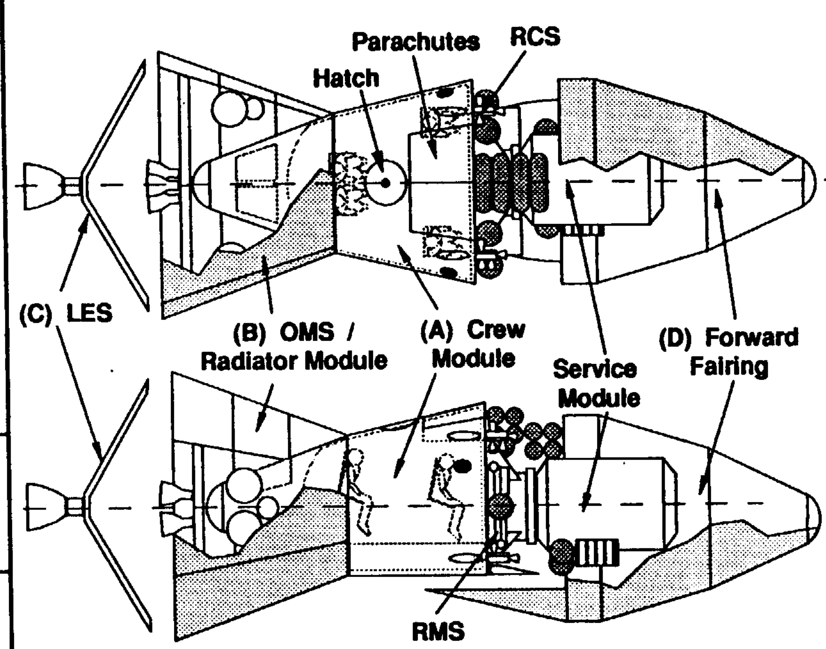
A Crew Module
B OMS / Radiator Module
C Launch Escape System (LES)
D Fwd Fairing

1 Includes Flight Crew + Equipment (600 Lb), Passengers +Equip (2400 Lb)And Propellant Reserves / Residuals

Figure 8.2-1 Design Mass Summary - Crew Rotation

Crew / Passengers: 2 / 2					Mission Duration : 7 Day
Functional System	**A**	**B**	**C**	**D**	
1. Structure	5707	1312	260	1747	
2. Protection	1220	71		239	
3. Propulsion	1422	1066	2058		
4. Power - Electrical	2550	188	40		
5. Control	121				
6. Avionics	1692				
7. Environment	1406	795			
8. Other - Personnel Provisions	1694				
Other - Landing, Aux Systems	4040	150	32	362	
9. Weight Growth Margin	2977	537	358	352	
Dry Mass	**22829**	**4119**	**2748**	**2700**	
10. Non- Cargo (See Note 1)	2073	957			
11. Cargo	0	0			
Inert Mass	**24902**	**5076**	**2748**	**2700**	
12. Non- Propellant Consumables	1212				
13. Propellant - Nominal	1312	3829			
Gross Mass	**27426**	**8905**	**2748**	**2700**	
	36331		5448		
Total Mass	**41779**				

Configuration: Flattened Biconic



Notes:
A Crew Module / Service Module
B OMS / Radiator Module
C Launch Escape System (LES)
D Fwd Fairing

All Mass In Pounds

1 Includes Flight Crew + Equipment (600 Lb), Passengers +Equip (600 Lb), And Propellant Reserves / Residuals

Figure 8.2-2 Design Mass Summary - Satellite Servicing

Table 8.2-1 Fluid Usage - Crew Rotation Mission (Page 1 of 2)

PERSONNEL LAUNCH SYSTEM FLUIDS Mission 1 (CREW ROTATION)	PERSONNEL LAUNCH SYSTEM	NOTE: ALL MASSES IN POUNDS

PROPULSION FEATURES	OMS	RCS	COLD GAS
PROPELLANT TYPE:	LOX / RP	H2O2 / RP	NITROGEN
TVAC(LBF EACH):	900	100	30
ISPVAC(SEC):	315	310	60
100%RPFR(PER ENGINE):	2.8571	0.323	0.500
NO OF ENGINES:	3	16	12
RESERVES GUIDELINE (%WT):	10	20	20

Non-prop consumable usage	
Fuel Cell Fluids (Lb/kW-hr)	0.8
Food (LB/M-DAY)	4.0
Water (LB/M-DAY)	4.0
O2 (LB/M-DAY)	2.0
O2 Prepress (LB)	14.0
N2 Prepress (LB)	63.0
Stored Waste (LB/M-DAY)	4.0

SUMMARY	Crew No.	Power kW	DELTA V OMS	DELTA V RCS	DELTA V Gas	Time Hrs	Propulsion fluids OMS	Propulsion fluids RCS	Propulsion fluids Gas	Power Fluids	ECLSS Consumables Coolant	ECLSS Consumables Food	ECLSS Consumables Water	ECLSS Consumables O2	ECLSS Consumables N2	Stored Waste	Total
Nominal Usage - Ascent	10	7.3	0	0	0	1.0	0	0	0	6	20	0	0	1	0	-2	25
Nominal Usage - prior to rendevous	10	7.3	539	30	0	2.0	1660	94	0	12	0	0	0	2	0	-3	1764
Nominal Usage - Rendevous (1st pass	10	7.3	0	50	10	11.0	0	151	156	64	0	40	0	9	1	-18	402
Nominal Usage - Docked	2	5.1	0	0	0	50.0	0	0	0	208	0	24	0	10	3	-19	
Nominal Usage - prior to reentry	10	7.3	450	20	0	6.0	1289	58	0	35	0	0	0	5	0	-10	
Nominal Usage - Reentry	10	7.3	0	46	0	2.0	0	104	0	12	20	0	0	2	0	-3	134
Overboard (nominal) - Liftoff to Landing			**989**	**146**	**10**	**72**	**2949**	**407**	**156**	**337**	**40**	**64**	**0**	**29**	**4**	**-56**	**3928**
Reserves - nominal mission							295	81	31	71	8	0	0	6	0		
Reserves - contingency operation							0	166	187	0	0	64	80	14	63		
Pre-liftoff Usage							0	0	0	0	0	0	0	0	0		
Usable, Incl Contingency							**3244**	**653**	**374**	**408**	**48**	**128**	**80**	**49**	**67**		
Residuals - In Module							0	0	0	0	0	0	0	14	63		
Residuals - in Tankage							73	33	43	12	5	0	8	0	0		
Residuals - in Feedlines							395	9	4	4	2	0	4	0	1		
Residuals - Pressurant							81	17	0	0	0	0	0	0	0		
Total Capacity							**3793**	**712**	**420**	**424**	**55**	**128**	**92**	**63**	**131**		

Table 8.2-1 Fluid Usage - Crew Rotation Mission (Page 2 of 2)

PERSONNEL LAUNCH SYSTEM FLUIDS — **PERSONNEL LAUNCH SYSTEM**
Mission 1 (CREW ROTATION)
NOTE: ALL MASSES IN POUNDS

ORBITAL SEQUENCE	Crew No.	Power kW	DELTA V			Time Hrs	Propulsion fluids			Power Fluids	ECLSS Consumables					Stored Waste	Dry Weight (LB)	Delta Weight (LB)	Total Weight (LB)
			OMS	RCS	Cold Gas		OMS	RCS	Cold Gas		Coolant	Food	Water	O2	N2				
Crew module - liftoff condition								712	0	424	55	128	92	63	131	0	18636	20241	
Personnel & Equipment	10																3000	3000	
Service Module / Prox-ops tanks									420	0							553	973	
OMS Pod - liftoff condition							3793										4119	7912	
Launch							3793	712	420	424	55	128	92	63	131	0	26308		32127
Liftoff-to-orbit fluids	10	7.3				1.0				-5.8	-20		0.0	-0.8	-0.1	1.7		-25	32102
Separation																			32102
RCS - Post-separation / settling	10	7.3		10		0.5		-32	0	-2.9			0.0	-0.4	0.0	0.8		-35	32067
OMS - Orbit Transfer	10	7.3	209			0.5	-655			-2.9			0.0	-0.4	0.0	0.8		-657	31410
RCS - Trim	10	7.3		10		0.5		-31	0	-2.9			0.0	-0.4	0.0	0.8		-34	31376
OMS - Orbit Circularization	10	7.3	330			0.5	-1005			-2.9			0.0	-0.4	0.0	0.8		-1008	30368
RCS - Trim	10	7.3		10		0.0		-30	0	0.0			0.0	0.0	0.0	0.0		-30	30338
Begin SSF rendevous																			30338
RCS - Rendevous	10	7.3		25	0	11.0		-76	0	-64.3		-40.0	0.0	-9.3	-0.6	18.3		-172	30166
Cold Gas - Docking	10	7.3		0	8	0.0		0	-125	0.0			0.0	0.0	0.0	0.0		-125	30041
SSF Dock																			30041
SSF personnel, equip egress	10	7.3				1.0				-5.8			0.0	-0.8	-0.1	1.7	-2400	-2405	27636
On-board activities	2	5.1				48.0				-196.6		-24.0	0.0	-8.6	-2.5	16.0		-216	27420
SSF personnel, equip ingress	10	7.3				1.0				-5.8			0.0	-0.8	-0.1	1.7	2400	2395	29815
Cold gas - Undock	10	7.3		0	2	0.0		0	-31	0.0			0.0	0.0	0.0	0.0		-31	29784
RCS - Vehicle alignment	10	7.3		25	0	0.0		-75	0	0.0			0.0	0.0	0.0	0.0		-75	29710
Prior to deorbit																			29710
RCS - Vehicle alignment	10	7.3		10	0	0.0		-30	0	0.0			0.0	0.0	0.0	0.0		-30	29680
OMS - Deorbit	10	7.3	450			6.0	-1289			-35.1			0.0	-5.1	-0.3	10.0		-1319	28361
Drop Satellite Service Equipment	0	0.0				0.0			-265	0.0			0.0	0.0	0.0	0.0	-553	-818	4302
RCS - OMS pod separation	10	7.3		10		0.0	-844	-28	0	0.0			0.0	0.0	0.0	0.0	-4119	-4992	22551
Begin Reentry																			22551
RCS - Reentry roll control	10	7.3		46		0.0		-104	0	0.0	-20		0.0	0.0	0.0	0.0		-124	22427
Deploy parachutes / Post Landing	10	7.3				2.0				-11.7			0.0	-1.7	-0.1	3.3	-862	-872	21555
PLS AT LANDING						72	0	306	0	87	15	64	92	34	127	56	20774		21555

Table 8.2-2 Fluid Usage - Satellite Servicing Mission (Page 1 of 2)

PERSONNEL LAUNCH SYSTEM FLUIDS
Mission 5 (SATELLITE SERVICE)

PERSONNEL LAUNCH SYSTEM

NOTE: ALL MASSES IN POUNDS

PROPULSION FEATURES	OMS	RCS	COLD GAS
PROPELLANT TYPE:	LOX / RP	H2O2 / RP	NITROGEN
TVAC(LBF EACH):	900	100	30
ISPVAC(SEC):	315	310	60
100%RPFR(PER ENGINE):	2.8571	0.323	0.500
NO OF ENGINES:	3	16	12
RESERVES GUIDELINE (%WT):	10	20	20

Non-propulsive consumable usage	
Fuel Cell Fluids (Lb/kw-hr)	0.8
Food (LBM-DAY)	4.0
Water (LBM-DAY)	4.0
O2 (LBM-DAY)	2.0
O2 Prepress (LB)	16.0
N2 Prepress (LB)	73.0
Stored Waste (LBM-DAY)	4.0

SUMMARY	Crew No.	Power kW	DELTA V OMS	DELTA V RCS	DELTA V Gas	Time Hrs	Propulsion fluids OMS	Propulsion fluids RCS	Propulsion fluids Gas	Power Fluids	ECLSS Consumables Coolant	ECLSS Consumables Food	ECLSS Consumables Water	ECLSS Consumables O2	ECLSS Consumables N2	Stored Waste	Total
Nominal Usage - Ascent	4	7.3	0	0	0	1	0	0	0	6	20	0	0	0	0	-1	26
Nominal Usage - on-orbit	4	7.3	1155	50	0	8	3834	165	0	47	0	0	0	3	0	-5	4044
Nominal Usage - Rendevous	4	4.9	0	212	20	144		702	342	564	0	96	0	54	29	-96	1691
Nominal Usage - Reentry	4	7.3	0	46	0	2		103	0	12	20	0	0	1	0	-1	134
Overboard (nominal) - Liftoff to Landing			1155	308	20	155	3834	970	342	629	40	96	0	58	29	-103	5895
Reserves - nominal mission							383	194	68	126	8	0	0	0	0		
Reserves - contingency operation							0	0	411	0	0	32	32	16	73		
Pre-liftoff Usage							0	0	0	0	0	0	0	0	0		
Usable, Incl Contingency							4218	1164	822	754	48	128	32	74	102		
Residuals - In Module							0	0	0	0	0	0	0	16	73		
Residuals - In Tankage							73	58	95	23	5	0	3	0	0		
Residuals - in Feedlines							395	16	8	8	2	0	2	1	1		
Residuals - Pressurant							106	31	0	0	0	0	0	0	0		
Total Capacity							4792	1269	925	785	55	128	37	91	177		

BOEING

Table 8.2-2 Fluid Usage - Satellite Servicing Mission (Page 2 of 2)

PERSONNEL LAUNCH SYSTEM FLUIDS — **PERSONNEL LAUNCH SYSTEM**
Mission 5 (SATELLITE SERVICE) — NOTE: ALL MASSES IN POUNDS

ORBITAL SEQUENCE	Crew No.	Power kW	DELTA V OMS	DELTA V RCS	DELTA V Cold Gas	Time Hrs	Propulsion fluids OMS	Propulsion fluids RCS	Propulsion fluids Cold Gas	Power Fluids	ECLSS Consumables Coolant	Food	Water	O2	N2	Stored Waste	Dry Weight (LB)	Delta Weight (LB)	Total Weight (LB)
Crew module - liftoff condition								1269	0	424	55	128	37	91	177	0	20138	22318	
Personnel & Equipment	4																1200	1200	
Service Module / Prox-ops tanks									925	361							2691	3976	
OMS Pod - liftoff condition							4792										4119	8911	
Launch							4792	1269	925	785	55	128	37	91	177	0	28148		36405
Liftoff-to-orbit fluids	4	7.3				1.0				-5.8	-20		0.0	-0.3	-0.1	0.7		-26	36380
Separation																			36380
RCS - Post-separation / settling	4	7.3		10		0.5		-36	0	-2.9			0.0	-0.2	0.0	0.3		-39	36340
OMS - Orbit Transfer	4	7.3	293			0.5	-1036			-2.9			0.0	-0.2	0.0	0.3		-1038	35302
RCS - Trim	4	7.3		10		0.5		-35	0	-2.9			0.0	-0.2	0.0	0.3		-38	35264
OMS - Orbit Circularization	4	7.3	412			0.5	-1405			-2.9			0.0	-0.2	0.0	0.3		-1408	33856
RCS - Trim	4	7.3		10		0.0		-34	0	0.0			0.0	0.0	0.0	0.0		-34	33822
Begin Satellite rendevous																			33822
RCS - Rendevous & dock	4	4.9		28	3	24.0		-95	-53	-94.1		-16.0	0.0	-10.3	-11.5	16.0		-263	33559
RCS - Undock	4	4.9		25	2	12.0		-84	-35	-47.0		-8.0	0.0	-4.2	-0.7	8.0		-171	33388
RCS - Rendevous & dock	4	4.9		28	3	24.0		-94	-52	-94.1		-16.0	0.0	-8.3	-1.5	16.0		-249	33139
RCS - Undock	4	4.9		25	2	12.0		-83	-34	-47.0		-8.0	0.0	-4.2	-0.7	8.0		-169	32970
RCS - Rendevous & dock	4	4.9		28	3	24.0		-92	-51	-94.1		-16.0	0.0	-10.3	-11.5	16.0		-259	32710
RCS - Undock	4	4.9		25	2	12.0		-82	-34	-47.0		-8.0	0.0	-4.2	-0.7	8.0		-168	32543
RCS - Rendevous & dock	4	4.9		28	3	24.0		-91	-51	-94.1		-16.0	0.0	-8.3	-1.5	16.0		-246	32297
RCS - Undock	4	4.9		25	2	12.0		-81	-33	-47.0		-8.0	0.0	-4.2	-0.7	8.0		-166	32131
Prior to deorbit																			32131
RCS - Vehicle alignment	4	7.3		10	0	0.0		-32	0	0.0			0.0	0.0	0.0	0.0		-32	32099
OMS - Deorbit	4	7.3	450			6.0	-1394			-35.0			0.0	-2.1	-0.4	4.0		-1428	30671
Drop Satellite Service Equipment	4	7.3				0.0			-582	0.0			0.0	0.0	0.0	0.0	-2691	-3273	27398
RCS - OMS pod separation	4	7.3		10		0.0	-957	-27	0	0.0			0.0	0.0	0.0	0.0	-4119	-5104	22294
Begin Reentry																			22294
RCS - Reentry roll control	4	7.3		46		0.0		-103	0	0.0	-20		0.0	0.0	0.0	0.0		-123	22172
Deploy parachutes / Post Landing	4	7.3				2.0				-11.7			0.0	-0.7	-0.1	1.3	-862	-873	21298
PLS AT LANDING						155	0	299	0	156	15	32	37	33	147	103	20476		21298

TPS - remains the same.

RCS - Four extra proximity operations nitrogen bottles (jettisoned prior to reentry) are added for the satellite service mission. Total weight change is +450 lbm.

EPS - Additional O_2/H_2 reactant bottles are added to the service module for the service mission (jettisoned prior to reentry).

Surface controls - remain the same.

Avionics - An RMS workstation is added for the satellite service mission. Total weight change is +55 lbm.

ECLSS - remains the same as the LiOH canister storage is sized by the service mission requirement of 4 persons for 7 days. Heat rejection and humidity control systems are sized by the larger crew rotation crew size (10).

Personnel provisions - For the service mission, a galley with food warmer and water dispenser as well as a commode are added (plumbing and electrical scar included in crew rotation design). Six crew seats are removed and four sleep stations are added. Net weight change is +159 lbm.

Auxiliary systems - Two remote manipulators, mission-specific tools, and two EVA suits are added for the service mission. Total weight change is +1386 lbm.

EVA - A 60 in. by 85 in. satellite servicing airlock is added for the service mission, along with extra fuel cell reactant tanks and spares equipment racks. Total weight change is +1620 lbm, including EPS reactant tanks and weight growth.

Table 8.2-3 Detailed Weight and Balance Statement (Page 1 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE	CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE	SATELLITE SERVICE XCG	REMARKS	WG%
PERSONNEL		10			4			
CREW		2			2			
PASSENGERS		8			2			
MISSION DURATION (DAYS)		3.0			7.0			
ECLSS								
CLOSURE LEVEL		OPEN			OPEN			
PRESSURIZED VOLUME -CABIN (FT3)		980.0			980.0			
PRESSURIZED VOLUME -AIRLOCK (FT3)		0.0			150.0			
PRESS/REPRESS EVENTS		2.0			2.0			
CABIN LEAKAGE (%VOLUME/DAY)		2.0			2.0			
PROPULSION		Delta V Isp,sec			Delta V Isp,sec			
RCS - H2O2/RP		146 310			328 310			
COLD GAS - N2		10 60			0			
OMS - LO2/RP		989 315			1155 315			
LES - Expend Liquid Pusher		606 310			606 310			
DESIGN ON-PAD ABORT WEIGHT		37567			41777.4			
DESIGN ON-ORBIT WEIGHT		32119			36329.9			
DESIGN LANDING WEIGHT		21567			21282			
STRUCTURE - BODY GROUP		5116	171		4823	165		15
FWD BODY		996			996			
BULKHEAD - STA 14	1	18	14	1	18	14	S- 8.73 SF @ 2.0 PSF	
MAJOR FRAME - STA 115	1	80	115	1	80	115	D,ave = 9.42 ft, A=3.0 in2 ALUMINUM	
MINOR FRAMES	4	82	65	4	82	65	L, ave = 8.5 ft, A=1.5 in2 ALUMINUM	
JOINTS, SPLICES, FASTENERS		27	65		27	65	15% OF FRAMES, BULKHEADS	
COVER PANELS, UPPER		116	75		116	75	S=68 SF @ 1.7 PSF ALUMINUM	
COVER PANELS, LOWER		160	75		160	75	S=94 SF @ 1.7 PSF ALUMINUM	
LONGERONS	6	126	65	6	126	65	L= 8.75 FT ea, A=2.0 IN2 ALUMINUM	
LANDING GEAR WELL & FRAMES		60	40		60	40	S=20 SF @ 3.0 PSF ALUMINUM	
LANDING GEAR SUPT STRUTS	4	82	40	4	82	40	L= 8.5 FT, A=2.0 IN2	
LANDING GEAR DOOR - STRUCTURE	1	21	40	1	21	40	S- 6.0 SF @ 3.5 PSF ALUMINUM	
LANDING GEAR DOOR - MECHANISM		38	40		38	40		
ACCESS PANELS	2	96	50	2	96	50	S- 16 SF EACH @3.0 PSF ALUMINUM	
LAUNCH/PROP MODULE UMBIL PLATE	1	30	115	1	30	115		
EQUIPMENT SUPPORT RACKS		60	50		60	50	S- 30 SF @ 2.0 PSF ALUMINUM	
MID/AFT BODY		1365			1365			
MAJOR FRAME - STA 230		155	230		155	230	D, ave = 13.7 ft, A=3.0 in2 ALUMINUM	
MINOR FRAMES	3	200	173	3	200	173	L, ave=37.0 ft, A=1.5 in2 ALUMINUM	
JOINTS, SPLICES, FASTENERS		53	173		53	173	15% OF FRAMES, BULKHEADS	
COVER PANELS, UPPER		240	175		240	175	S=141 SF @ 1.7 PSF ALUMINUM	
COVER PANELS, LOWER		307	175		307	175	S=180 SF @ 1.7 PSF ALUMINUM	
LONGERONS	6	138	173	6	138	173	L=9.6 FT, A=2.0 IN2 ALUMINUM	
FTGS, CABIN ATTACHMENT	22	33	175	22	33	175		
WINDOW, THERMAL	2	14	210	2	14	210	S=0.8 SF EA @ 9.0 PSF	
WINDOW, RETAINER	2	5	210	2	5	210		
PARACHUTE COVER PANELS	2	72	200	2	72	200	S- 12 SF EACH @3.0 PSF ALUMINUM	
PARACHUTE COVER ACTUATORS	4	16	200	4	16	200		
SERVICE MODULE UMBILICAL PLATE	1	20	260	1	20	260		
RMS GRAPPLE FITTING	2	44	235	2	44	235		
BODY FLAP CLOSEOUT/HINGE SUPT	1	68	230	1	68	230	S=7.5 SF @ 9.0 PSF	

Table 8.2-3 Detailed Weight and Balance Statement (Page 2 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE			SATELLITE SERVICE XCG	REMARKS		WG%
PRESSURIZED CABIN			2478					2183				ALUMINUM SKIN / STRINGER	
BULKHEAD, FWD	1	60			110	1	60			110	S=30 SF @ 2.0 PSF	ALUMINUM	
BULKHEAD, STA 226	1	330			226	1	330			226	S= 110 SF @ 3.0 PSF	ALUMINUM	
GUSSETS, AFT BULKHEAD	4	60			240	4	60			240	S= 20 SF TOTAL@ 3.0 PSF	ALUMINUM	
MINOR FRAMES, CABIN	3	175			173	3	175			173	L, ave= 32.4 FT, A= 1.5 IN2	ALUMINUM	
MINOR FRAMES, TUNNEL	2	45			248	2	45			248	L= 12.5 ft, A=1.5 in2	ALUMINUM	
COVER PANELS, UPPER		297			170		297			170	S=175 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, LOWER		322			170		322			170	S= 189 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, TUNNEL		54			248		54			248	S=36 SF @ 1.5 PSF	ALUMINUM	
PARTITION, STA 100	1	75			100	1	75			100	S= 63.2 SF, @ 1.2 PSF	COMPOSITE	
EQUIPMENT SUPPORT RACKS		150			95		150			95	S=100 SF @ 1.5 PSF		
FLOORING, EQUIP SUPT		184			173		184			173	S= 92 SF @ 2.0 PSF	ALUMINUM	
FTGS, CABIN ATTACHMENT	22	33			173	22	33			173			
LATERAL WINDOWS	2	43			210	2	43			210	S= 0.8 SF EA @ 27 PSF		
LATERAL WINDOWS, RETAINER	2	21			210	2	21			210			
AFT WINDOWS	2	43			226	2	43			226	S= 0.8 SF EA @ 27 PSF		
AFT WINDOWS, RETAINER	2	21			226	2	21			226			
DOCKING ADAPTER MECHANISM	1	340			263	0	0			0			
AIRLOCK INTERFACE RING	0	0			0	1	47			258	L= 13.0 FT, A= 2.5 IN2 + 20%	ALUMINUM	
TOP HATCH, STRUCTURE	1	58			150	1	58			150	36-IN DIA		
TOP HATCH, MECHANISM		32			150		32			150			
DOCKING HATCH, STRUCTURE	1	72			260	1	72			260	40-IN DIA, SHUTTLE-TYPE		
DOCKING HATCH, WINDOW & RETAINER	1	20			260	1	20			260			
DOCKING HATCH, MECHANISM		41			260		41			260			
BODY FLAP	1		279		250	1		279		250	S= 31 SF @ 9.0 PSF	RCC/ INSTL	
PROTECTION				1220	127				1220	127			15
EXTERNAL TPS			919					919					
NOSE CAP, PANELS (ZONE 1)		65			10		65			10	S= 13.0 SF @ 5 PSF	RCC/INSTL	
NOSE CAP, INSTL HDWARE		39			14		39			14	60% OF RCC WEIGHT		
NOSE CAP, BULK INSULATION		53			14		53			14	S=8.8 SF @ 6.0 PSF		
BODY TPS, ZONE 2		161			75		161			75	S=61 SF @ 2.64 PSF	FRCI-12 w/SiC cover	
LANDING PAD DOOR TPS (ZONE 2)		17			75		17			75	S=6 SF @ 2.8 PSF, incl closeouts	FRCI-12 w/SiC cover	
BODY TPS, ZONE 3		399			175		399			175	S=283 SF @ 1.41 PSF	FRCI-12	
BODY TPS, ZONE 4		81			75		81			75	S=155 SF @ .522 PSF	Rigid TABI	
ACCESS PANEL TPS (ZONE 4)		17			175		17			175	S= 32 SF @ .522 PSF	Rigid TABI	
PARACHUTE COVER TPS (ZONE 4)		13			175		13			175	S=24 SF @ 0.522 PSF	Rigid TABI	
AFT BULKHEAD TPS, ZONE 5		74			230		74			230	S=184 SF @ 0.40 PSF	Rigid TABI	
INTERNAL INSULATION / TCS			220					220					
BULK INSULATION - FWD BODY		43			75		43			75	S= 124 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSULATION - FWD BODY		9			75		9			75	S= 124 SF @ 0.07 PSF	MLI	
BULK INSULATION - CABIN		140			175		140			175	S= 401 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSULATION - CABIN		28			175		28			175	S= 401 SF @ 0.07 PSF	MLI	
PURGE AND VENT SYSTEM			63					63			SCALED FROM SHUTTLE		
DUCTING		30			75		30			75			
VALVES		20			75		20			75			
SUPPORT, INSTALLATION		13			75		13			75			
WINDOW / HATCH CONDITIONING			19					19			SCALED FROM SHUTTLE		
PLUMBING		7			220		7			220			
DESSICANT, VALVES, DISCONNECTS		8			220		8			220			
SUPPORT, INSTALLATION		4			220		4			220			

Table 8.2-3 Detailed Weight and Balance Statement (Page 3 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)
NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE			SATELLITE SERVICE XCG	REMARKS	WG%
PROPULSION - REACTION CONTROL				972	241				1422	251	H2O2 / RP SYSTEM; EXTERNAL PRESS	15
THRUSTER MODULES			196		235			196		235		
THRUSTERS - RCS	16	133				16	133					
THRUSTERS - COLD GAS	12	45				12	45				MOOG 5264 - 30 LBF N2 THRUSTERS	
THRUSTER MODULE SUPPORT	4	18				4	18				10 % OF SYS	
PRESSURIZATION SYSTEM			66		240			66		240		
GN2 BOTTLE(S) - RCS	1	28				1	28				SCI 1270365 BOTTLE @ 4500 PSI KEVLAR O/W TI	
REGULATORS	2	9				2	9				FAIRCHILD	
FILL & DRAIN DISCONNECTS	1	1				1	1				PYRONETICS	
MANIFOLD/PLUMBING		10					10				BOEING	
TANK VENT / RELIEF		9					9					
PRESS SYS SUPPORT		9					9				15 % OF SYS	
PROPELLANT SUPPLY - RCS			193		240			193		240		
TANKAGE - H2O2	2	60				2	60					
TANKAGE - RP	1	15				1	15					
VALVES	9	35				9	35				CONSOLIDATED CONTROLS	
MANIFOLD/PLUMBING	1	40				1	40				BOEING 304L SS	
TANK FILL, VENT & DRAIN	2	25				2	25					
PROPELLANT SUPPLY SUPPORT		18					18				10 % OF SYS	
PROPELLANT SUPPLY - PROX OPS (fixed)			36		245			36		245		
FLIGHT DISCONNECTS	1	1				1	1				PYRONETICS	
MANIFOLD/PLUMBING		32					32				BOEING 304L SS	
COLD GAS SUPPLY SUPPORT		3					3				10 % OF SYS	
PROPELLANT SUPPLY - PROX-OPS (expend)			481					931				
N2 BOTTLE(S) - COLD GAS	4	310			250	8	620			270	BRUNSWICK 220064, (26.3 IN ID) KEVLAR O/W TI	
VALVES	16	82			230	32	165			230	CONSOLIDATED CONTROLS	
FLIGHT DISCONNECT	1	1			230	1	1			230	PYRONETICS	
FILL / DRAIN DISCONNECT	4	4			250	4	4			270	PYRONETICS	
MANIFOLD/PLUMBING		10			230		20			230	BOEING 304L SS	
TANK VENT / RELIEF		14			250		20			270		
TANK SEPARATION	4	16			230	4	16			230	EXPLOSIVE BOLTS	
COLD GAS SUPPLY SUPPORT		44			230		85			230	10 % OF SYS	

Table 8.2-3 Detailed Weight and Balance Statement (Page 4 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)
NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE			SATELLITE SERVICE XCG	REMARKS	WG%
POWER - ELECTRICAL				2157	62				2157	62		15
POWER SUPPLY			1300					1300			FUEL CELL SYSTEM - 6 KW NOM, 9 KW PEAK TOTAL	
FUEL CELLS	2	361			45	2	361			45	Reduced Shuttle Cells - 2 of 3 to supply sustained power	
BATTERIES	6	432			25	6	432			25	Contingency only - 48 kw-hr LI-SOCL2	
O2 TANKAGE (EPS & ECLSS)	2	90			70	2	90			70	20.0 in ID VACUUM -JACKETED TANK	
H2 TANKAGE	2	94			70	2	94			70	24.0 in ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	4	12			70	4	12			70		
REACTANT RELIEF, VENT PLUMBING	4	64			70	4	64			70		
REACTANT SUPPLY PLUMBING	4	20			60	4	20			60		
REACTANT SUPPLY VALVES, DISC	4	12			60	4	12			60		
COOLANT PLUMBING		45			55		45			55	INCL. 30 LB FLUIDS	
POWER SUPPLY SUPT/INSTL		170			60		170			60	15 % OF SYS	
POWER DIST EQUIP			169					169				
POWER DISTRIBUTION PANELS	3	99			45	3	99			45		
10VDC POWER SUPPLY	3	1			45	3	1			45		
EXTERIOR LIGHTS		15			230		15			230	ESTIMATE	
INTERIOR LIGHTS		20			150		20			150	ESTIMATE	
POWER DISTRIBUTION SUPT/INSTL		34			100		34			100	25 % OF SYS	
WIRING			688					688			ESTIMATE	
POWER DISTR. WIRE HARNESSES		400			95		400			95		
INSTRUMENTATION WIRING		100			40		100			40		
ELECTRICAL CONNECTORS		50			95		50			95	BULKHEAD FEEDTHRU PLATES	
HARNESS SUPT/INSTL		138			90		138			90	25 % OF SYS	
SURFACE CONTROLS				121	240				121	240		15
BODY FLAP ACTUATION			121					121			DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110			240	2	110			240		
ACTUATOR SUPT/INSTL		11			240		11			240	10 % OF SYS	

Table 8.2-3 Detailed Weight and Balance Statement (Page 5 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE			SATELLITE SERVICE XCG	REMARKS	WG%
AVIONICS				1637	127				1692	129		15
GUIDANCE, NAVIGATION AND CONTROL			229					229				
FAULT-TOLERANT NAVIGATOR	1	50			95	1	50			95		
GPS RECEIVER	2	12			95	2	12			95		
GPS ANTENNAS	2	10			240	2	10			240		
HORIZON SCANNER	2	12			240	2	12			240		
RADAR ALTIMETER	2	10			240	2	10			240		
BODY FLAP DRIVER	1	45			230	1	45			230		
RCS/ OMS VALVE DRIVER	2	90			95	2	90			95		
RENDEVOUS AND DOCK			133					133				
RENDEVOUS RADAR	1	30			235	1	30			235		
RADAR SIGNAL PROCESSOR	1	70			200	1	70			200		
ANTENNA	1	8			235	1	8			235		
ANTENNA MAST, DEPLOYMENT MECHS	1	25			235	1	25			235		
VEHICLE HEALTH MONITORING			75					75			SENSORS INCL IN INSTRUMENTATION COUNT	
MASS MEMORY	3	75			40	3	75			40		
COMMUNICATIONS AND TRACKING			238		95			238		95		
CENTRAL DATA FORMATTER	1	27				1	27					
TRANSPONDER	1	16				1	16					
POWER AMP	1	18				1	18					
DIPLEXER, RF SWITCH	1	3				1	3					
AUDIO	1	40				1	40					
UHF TRANSCEIVER	1	20				1	20					
ANTENNAS	3	24				3	24					
SEARCH AND RESCUE RADIO	1	40				1	40				ESTIMATED	
SIGNAL CABLING		50					50				ESTIMATED	
CONTROLS AND DISPLAYS			185		210			235		210		
RECONFIG DISPLAYS / CONTROL UNITS	5	50				5	50					
ELECTRONIC INTERFACES	3	75				3	75					
RECONFIG. PUSH-BUTTON PANEL	3	30				3	30					
RMS WORKSTATION	0	0				1	50				ESTIMATE FOR SERVICING MISSION	
HAND CONTROLLERS	2	30				2	30					
INSTRUMENTATION			83		40			83		40		
SENSOR INTERFACE UNIT (SIU)	60	30				60	30					
NETWORK INTERFACE UNIT (NIU)	2	3				2	3					
SENSORS, INSTRUMENTATION	700	50				700	50					
DATA HANDLING			463		95			463		95		
FAULT TOLERANT PROCESSOR	3	99				3	99					
MASS MEMORY	3	75				3	75					
DATA BUS COUPLERS	60	30				60	30				ESTIMATED	
MDM	7	259				7	259					
STRUCTURES/MECHS CONTROLS			82					82				
CHUTE, LANDING GEAR CONTROLLER	1	61			200	1	61			200		
LASER FIRING UNIT	2	20			95	2	20			95		
LASER INITIATORS	5	1			95	5	1			95		
AVIONICS SUPT/INSTL			149		134			154		134	10 % OF AVIONICS	

BOEING

Table 8.2-3 Detailed Weight and Balance Statement (Page 6 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE			SATELLITE SERVICE XCG	REMARKS	WG%
ENVIRONMENTAL CONTROL				1406	104				1406	104		15
CABIN AND PERSONNEL SYSTEM			416					416				
O2 TANKAGE - CRYO STORAGE	0	0				0	0				INCL IN FUEL CELL REACTANT STORAGE	
O2 TANKAGE - (GAS FOR REPRESS)	1	15			200	1	15			200	Kevlar / Inconel	
N2 TANKAGE - (GAS FOR REPRESS)	2	60			200	2	60			200	Kevlar / Titanium	
PRESS PLUMBING		12			190		12			190		
CABIN PRESS & COMPOSITION CNTRLS		65			170		65			170	VALVES, VENT RELIEF VALVES, ETC	
CO2 REMOVAL - 2-BED LiOH		11			130		11			130	LiOH CANISTER UNIT - 2 CANISTER UNIT	
LiOH CANISTER STORAGE		100			100		100			100	(20 / 28 M-DAY)	
TEMP AND HUMIDITY CONTROL		127			110		127			110	FANS/SEPARATORS, HEAT EXCHANGER, ETC	
TRACE CONTAMINANT CONTROL		7			130		7			130	CANISTER FOR IMPURITY REMOVAL	
DUCTING, MISC		20			130		20			130	FANS INCLUDED IN TEMPERATURE CONTROL	
EQUIPMENT COOLING			209					209				
EQUIPMENT COLD PLATES		120			95		120			95	S= 60 SF @ 2.0 PSF	
AVIONICS COOLING ASSY		28			95		28			95	INCL HX, FANS, DUCTING	
IMU HEAT EXCHANGER ASSY	1	31			95	1	31			95		
PLUMBING		20			95		20			95		
DUCTING, MISC		10			95		10			95	FANS INCLUDED IN TEMPERATURE CONTROL	
HEAT TRANSFER WATER LOOP			161					161				
HEAT EXCHANGER - POTABLE WATER	1	17			100	1	17			100	BASED ON SHUTTLE	
PRIMARY, SECONDARY WATER PUMPS		78			100		78			100		
PLUMBING		30			100		30			100		
COOLANT IN LOOP - WATER		36			100		36			100		
HEAT TRANSFER FREON LOOP			270					270				
HEAT EXCHANGER - WATER-FREON	1	50			90	1	50			90	BASED ON SHUTTLE	
HEAT EXCHANGER - GSE	1	50			90	1	50			90	BASED ON SHUTTLE	
HEAT EXCHANGER - FUEL CELL	1	50			45	1	50			45	BASED ON SHUTTLE	
FREON PUMP PACKAGE	2	90			90	2	90			90		
COOLANT IN LOOP - FREON		30			90		30			90		
HEAT REJECTION			222					222				
AMMONIA BOILER ASSEMBLY		45			40		45			40	INCL AMMONIA TANK, HEAT EXCHNGR, VENT, VALVES	
COOLANT TANKAGE - WATER		14			90		14			90		
FLASH EVAPORATOR - WATER		58			80		58			80	FROM SHUTTLE	
TOPPING DUCT ASSEMBLY		78			100		78			100		
HIGH LOAD DUCT ASSEMBLY		27			100		27			100		
RADIATOR PANELS			0					0			INCL ON PROPULSION MODULE	
ECLSS SUPT/INSTL			128		104			128		104	10 % OF ECLSS	

Table 8.2-3 Detailed Weight and Balance Statement (Page 7 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE			SATELLITE SERVICE XCG	REMARKS	WG%
OTHER - PERSONNELPROVISIONS				1535	150				1694	140		15
FOOD MANAGEMENT			117					283				
GALLEY		0			130		166			130	GALLEY UNIT, WITH WATER DISPENSER	
FOOD STORAGE UNITS		117			150		117			150		
WATER MANAGEMENT			85		100			62		100		
WATER STORAGE TANK		50					50				FOR POTABLE WATER STORAGE	
HANDWASH - WET WIPES		2					2					
WATER DISPENSER		23					0				WATER DISPENSER ONLY	
PLUMBING, VALVES, ETC		10					10					
WASTE MANAGEMENT			80		115			230		115		
WASTE WATER TANK		50					50					
COMMODE SYSTEM		15					165				Installation scar only for crew rotation	
EMERGENCY WASTE COLLECTION		15					15				SHUTTLE TYPE	
FIRE DETECTION / SUPPRESSION			13		100			13		100		
SMOKE DETECTORS		7					7					
FIRE SUPPRESSION TANK		6					6				INCLUDES SUPPRESSANT	
FURNISHINGS AND EQUIPMENT			1100					952				
SEATS, PERSONNEL RESTRAINTS	4	400			190	2	200			190	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	4	400			150	0	0			150	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			110	2	200			110	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SLEEP STATIONS		0				4	512			150	NOT REQUIRED FOR TRANSFER	
INCIDENTAL EQUIPMENT	10	100			150	4	40			150	STORAGE FOR ASTRONAUT PERSONAL EFFECTS	
SUPPORT/INSTALLATION			140		152			154		142	10 % OF ECLSS	
OTHER - RECOVERY & AUXILIARY				2522	194				3908	196		15
PARACHUTE SYSTEM			1726					1726				
DROGUE CHUTES	1	290			200	1	290			200	12 + 0.00423 LB/LB INFLATION LOAD x 3g (MAX)	
BACKUP DROGUE	1	290			200	1	290			200		
MAIN CHUTE - HI-GLIDE	1	444			200	1	444			200	0.020 LB/LB INFLATION LOAD (MAX) @ 22 FPS	
BACKUP CHUTES - HI-GLIDE	1	444			200	1	444			200		
PARACHUTE CNTRL SPINDLE, MOTORS	2	100			200	2	100			200	ESTIMATE	
PARACHUTE SUPT/INSTL		157			200		157			200	10 % OF SYSTEM	
LANDING SYSTEM			606					606				
NOSE LANDING GEAR	1	108			40	1	108			40	0.005 LB/LB DESIGN LANDING WT (MAX)	
AFT LANDING GEAR	2	431			220	2	431			220	0.02 LB/LB DESIGN LANDING WT (MAX)	
FLOTATION COLLAR AIRBAGS	4	12			240	4	12			240		
LANDING GEAR SUPT/INSTL		55			202		55			202	10 % OF SYSTEM	
SATELLITE SERVICE MODIFICATIONS			0					1386				
LARGE RMS	0	0				1	450			240		
SMALL RMS	0	0				1	300			240		
TOOLS, MISCELLANEOUS	0	0				1	100			150		
EVA SUITS, WITH EXPENDABLES	0	0				2	536			150		
SEPARATION			190					190				
PARACHUTE COVERS SEPARATION	2	40			200	2	40			200	L-20 FT @ 2.0 LB/FT	
FWD FAIRING SEPARATION		60			230		60			230	L-20 FT @ 2.0 LB/FT	
LAUNCH VEHICLE SEP BOLTS	6	90			115	6	90			115		
CREW MOD DRY, EXCL GROWTH				16686	150				18443	154		15
WEIGHT GROWTH MARGIN				2503	150				2766	154	15 % OF DRY WT	

Table 8.2-3 Detailed Weight and Balance Statement (Page 8 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE			SATELLITE SERVICE XCG	REMARKS	WG%
CREW MODULE DRY WEIGHT				19189	150				21209	154		
NON- CARGO ITEMS				3583	174				2073	194		
CREW, WITH EQUIPMENT			3000					1200				
FLIGHT CREW / personal effects	2	600			200	2	600			200	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			190	0	0			190	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	4	1200			150	0	0			150	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			110	2	600			110	90TH PERCENTILE + 107 lb ea.	
PROPELLANT RESIDUALS			103					199				
RCS RESIDUAL BI-PROP		42			235		74			235	RESIDUAL IN TANKS AND LINES	
RCS N2 PRESSURANT		18			235		31			235		
COLD GAS RESIDUALS		43			250		94			270		
PROPELLANT RESERVES			479					673				
RCS RESERVES - BIPROP		261			240		194			240	20% OF NOMINAL PROPELLANT	
RCS RESERVES - COLD GAS		218			250		479			250	20% OF NOMINAL PROPELLANT	
PAYLOAD / CARGO				0					0		NO CARGO CAPABILITY	
CREW MODULE INERT WEIGHT				22772	154				23281	157		
NON- PROPELLANT				873	109				1212	183		
IN-FLIGHT LOSSES			422					785			(CR- 264 KW-HR; SS- 840 KW-HR)	
FUEL CELL NOMINAL O2		300			70		559			193	0.71 LB/ KW -HR	
FUEL CELL NOMINAL H2		38			70		70			193	0.09 LB/ KW-HR	
FUEL CELL O2 RESERVES		60			70		112			193	20% NOMINAL	
FUEL CELL H2 RESERVES		8			70		14			193	20% NOMINAL	
FUEL CELL RESIDUAL REACTANT		16			70		30			193	ESTIMATE	
LIFE SUPPORT CONSUMABLES			451					427				
O2 - CRYO STORAGE		35			70		54			193	METABOLIC CONSUMPT. (2 LB/M-DAY) +20%+LEAKAGE	
O2 - GAS FOR REPRESSURIZATION		14			200		14			200	LEAK (0.38 LB/DAY)	
O2 - CABIN PRESSURIZATION		14			200		14			200		
N2 - GAS FOR REPRESS, LOSSES		67			200		72			200	LEAK (1.26 LB/DAY)	
N2 - CABIN PRESSURIZATION		63			200		63			200		
FOOD		128			150		128			150	4 LB/M-DAY	
POTABLE WATER		80			100		32			100	4 LB/M-DAY --48 HR CONTINGENCY ONLY	
HYGIENE WATER		0			100		0			100	PROVIDED BY FUEL CELL OUPUT	
EQUIP COOLING FLUIDS		50			90		50			90	WATER FOR LAUNCH & REENTRY COOLING ONLY + 20 %	
PROPELLANT - NOMINAL				563	243				1312	248		
RCS NOM PROPELLANT - BIPROP			407		240			970		240		
RCS NOM PROPELLANT - COLD GAS			156		250			342		270		
OMS FLUIDS			0					0			INCL IN JETTISONABLE OMS POD	
GROSS WEIGHT, LESS OMS				24208	154				25806	163		

Table 8.2-3 Detailed Weight and Balance Statement (Page 9 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION					SATELLITE SERVICE					REMARKS	WG%
	QTY	VALUE			XCG	QTY	VALUE			XCG		
SATELLITE SERVICE MODULE				0	0				1620	312		
STRUCTURE			0					884				
CREW MODULE INTERFACE RING	0	0				1	47			258	L= 13.0 FT, A= 2.5 IN2 + 20% ALUMINUM	
AIRLOCK MODULE, LESS HATCH	0	0				1	650			315	ALUMINUM	
AIRLOCK HATCH, STRUCTURE	0	0				1	72			360		
AIRLOCK HATCH, MECHANISM	0	0				1	45			360		
TOOL, EQUIPMENT SUPPORT	0	0					50			315		
CREW MODULE UMBILICAL PLATE	0	0				1	20			260		
POWER - ELECTRICAL			0					393				
O2 TANKAGE (EPS & ECLSS)	0	0				2	90			315	20.0 in ID VACUUM -JACKETED TANK	
H2 TANKAGE	0	0				2	94			315	24.0 in ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	0	0				4	12			315		
REACTANT RELIEF, VENT PLUMBING	0	0				4	64			315		
REACTANT SUPPLY PLUMBING	0	0				4	20			315		
REACTANT SUPPLY VALVES, DISC	0	0				4	12			315		
WIRE HARNESS, LIGHTING, ETC	0	0					50			315		
POWER SUPPLY SUPT/INSTL		0					51			315	15 % OF SYS	
OTHER - SEPARATION			0					32			SEPARATION BOLTS	
AIRLOCK SEPARATION	0	0			260	8	32			260		
OTHER - AUXILIARY SYSTEMS			0					100				
LARGE RMS	0	0				0	0				INCL IN MODULE	
SMALL RMS	0	0				0	0				INCL IN MODULE	
SPARES, SUPPORT EQUIPMENT	0	0					100			315		
EVA SUITS, WITH EXPENDABLES	0	0				0	0				INCL IN MODULE	
WEIGHT GROWTH MARGIN			0		245			211		290	15 % OF HARDWARE	

Table 8.2-3 Detailed Weight and Balance Statement (Page 10 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE			SATELLITE SERVICE XCG	REMARKS	WG%
PROPULSION / RADIATOR MODULE				4119	34				4119	34		
STRUCTURE			1312					1312				
AFT ADAPTER INTERFACE RING	1	158			-20	1	158			-20	L=43 FT, A=3.0 IN2 ALUMINUM	
CREW MODULE INTERFACE RING	1	92			115	1	92			115	L=30.6 FT, A=2.5 IN2 ALUMINUM	
MINOR FRAMES	2	134			48	2	134			48	L=37.3 FT, A=1.5 IN2 ALUMINUM	
LONGERONS	6	257			48	6	257			48	L=11.9 FT, A=3.0 IN2 ALUMINUM	
INTERMEDIATE STRUTS / FTGS	18	248			48	18	248			48	L ave=7.1 FT, A=1.0 IN2 +1.0 LB FTGS ALUMINUM	
RADIATOR PANEL LINKAGE & HINGES	2	40			48	2	40			48		
LAUNCH / CREW MOD UMBIL PLATES	2	60			48	2	60			48		
THRUST STRUCTURE	1	95			-5	1	95			-5	L=22 FT, A=3.0 IN2 +20% ALUMINUM	
THRUST STR STABILIZING STRUTS	6	48			-5	6	48			-5		
THRUST RING / FTGS	1	25			-5	1	25			-5	D=40 IN, A=2.0 IN2 ALUMINUM	
ENG INTERFACE FTGS	3	9			-7	3	9			-7	ESTIMATE	
TANK SUPPORT STRUTS	8	66			39	8	66			39	L= 72 IN, A=1.0 IN2 + 1 LB FTGS EA ALUMINUM	
TANK SWAY STRUTS	16	72			39	16	72			39	L=40 IN, A=1.0 IN2 + 1 LB FTG EA ALUMINUM	
PRESS TANK SUPT FLANGES	8	8			22	8	8			22	ESTIMATE ALUMINUM	
THERMAL PROTECTION			71		50			71		50	S= 1034 SF, @ 0.0685 PSF FOSR	
PROPULSION - OMS			1066					1066			LO2/RP SYSTEM; EXTERNAL PRESS	
ENGINES	3	150			-13	3	150			-13		
ENGINE MOUNT	3	15			-3	3	15			-3		
LO2 SYSTEM - TANK	2	93			39	2	93			39	41.0 in ID TANK, WITH INSULATION ALUMINUM	
LO2 SYSTEM - VALVES	6	24			4	6	24			4		
LO2 SYSTEM - MANIFOLD	1	144			8	1	144			8	24 FT @ 5.8 LB/FT + 5 FT @ 1 LB/FT ALUMINUM	
LO2 SYSTEM - LES VALVES	1	20			-10	1	20			-10		
LO2 SYSTEM - LES DISCONNECT	1	12			-30	1	12			-30		
LO2 SYSTEM - FILL, DRAIN, VENT	1	24			39		24			39		
LO2 SYSTEM - SUPPORT, INSTL		48			39		48			39	15 % OF OMS	
RP SYSTEM - TANK	2	115			39	2	115			39	35.0 in ID TANK, WITH INSULATION ALUMINUM	
RP SYSTEM - VALVES	6	24			4	6	24			4		
RP SYSTEM - MANIFOLD	1	89			8	1	89			8	24 FT @ 3.5 LB/FT + 5.0 FT @ 1 LB/FT ALUMINUM	
RP SYSTEM - LES VALVES	1	20			-10	1	20			-10		
RP SYSTEM - LES DISCONNECT	1	12			-30	1	12			-30		
RP SYSTEM - FILL, DRAIN, VENT	1	24			39		24			39		
RP SYSTEM - SUPPORT, INSTL		43			39		43			39	15 % OF OMS	
GN2 BOTTLES - OMS	2	128			22	2	128			22	SCI 1270365 , 4500 PSI	
GAS VALVES	4	18			8	4	18			8	MOOG	
REGULATORS	2	9			8	2	9			8	FAIRCHILD	
FILL & DRAIN DISCONNECTS	2	2			22	2	2			22	PYRONETICS	
MANIFOLD/PLUMBING		10			8		10			8	BOEING 304L SS	
BOTTLE VENT / RELIEF		17			22		17			22	FAIRCHILD	
PRESS SYSTEM SUPPORT		25			8		25			8	15 % OF OMS	
POWER DISTRIBUTION			188		48			188		48		
WIRING, INCL GROUND UMBILICALS		150					150					
EQUIPMENT SUPPORT/INSTL		38					38				25 % OF WIRING	
ECLSS RADIATOR PANELS			795		50			795		50	ALUMINUM	
COOLANT IN PANELS - FREON		30					30					
FIXED PANELS	2	304				2	304				A=134 sf ea @ 1.14 psf ALUMINUM	
DEPLOYED PANELS	2	461				2	461				A=134 sf ea (134 sf ea side) @ 1.72 psf ALUMINUM	
OTHER - AUXILIARY SYSTEMS			150					150				
LAUNCH VEHICLE SEPARATION	6	90			-26		90			-26	EXPLOSIVE BOLT SEPARATION	
CREW MODULE SEPARATION	6	60			115	6	60			115	EXPLOSIVE BOLT SEPARATION	
WEIGHT GROWTH MARGIN			537		35			537		35	15 % OF HARDWARE	

Table 8.2-3 Detailed Weight and Balance Statement (Page 11 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE		CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE		SATELLITE SERVICE XCG	REMARKS	WG%
OMS PROPELLANTS			3793	39			4786	39		
OMS RESIDUALS			549	39			574	39		
RESIDUALS - IN TANKS		73				73			0.3 FT3 PER TANK	
RESIDUALS - IN LINES, ENGINES		395				395			24 FT EA, 5.0 IN DIA.	
PRESSURANTS		81				106			0.0251 LB/LB PROPELLANT NITROGEN	
OMS RESERVES			295	39			383	39		
RESERVE PROPELLANT		295				383			10% OF NOMINAL	
OMS NOMINAL PROPELLANT			2949	39			3829	39	DELTA V AS SHOWN	
ON-ORBIT GROSS WEIGHT			32119	125			36330	139		
LAUNCH VEHICLE ADAPTER			1956	-79			1956	-79		
STRUCTURE			1363	-79			1363	-79	S- 545 SF @ 2.5 PSF ALUM SKIN/STR	
PROTECTION - THERMAL			0	-79			0	-79		
POWER - WIRE HARNESS			188	-79			188	-79	L- 8 FT, INCL CONNECTORS, ETC	
OTHER - CREW MOD SEPARATION SYS	6		150	-79	6		150	-79	SEP BOLTS	
WEIGHT GROWTH MARGIN			255	-79			255	-79	15 % OF HARDWARE	
FORWARD FAIRING			2700	315			2700	315		
STRUCTURE			1747				1747			
FAIRING NOSE CAP		45		504		45		504	S- 15 SF @ 3.0 PSF	
FAIRING - CONIC SECTION		1148		348		1148		348	S- 574 SF @ 2.0 PSF AL SKIN/STRNGR	
FAIRING - CYLINDRICAL SECTION		444		250		444		250	S- 222 SF @ 2.0 PSF AL SKIN/STRNGR	
FAIRING - FLAT SECTION COVER		110		250		110		250	S- 55 SF @ 2.0 PSF AL SKIN/STRNGR	
PROTECTION - THERMAL			239	348			239	348	S-796 SF @ 0.3 PSF SPRAY-ON FOAM	
OTHER - AUXILIARY SYS			362				362			
SEPARATION JOINTS		212		230		212		230	L- 106 FT @ 2.0 LB/FT SUPER-ZIP	
SEPARATION SPRINGS/FTGS		150		230		150		230	ESTIMATE	
WEIGHT GROWTH MARGIN			352	348			352	348	15 % OF HARDWARE	
BALLAST			0	0			0	0		
FWD NOSE BALLAST			0	900			0	900		

Table 8.2-3 Detailed Weight and Balance Statement (Page 12 of 12)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE	CREW ROTATION XCG	SATELLITE SERVICE QTY	SATELLITE SERVICE VALUE	SATELLITE SERVICE XCG	REMARKS	WG%
EXPENDABLE LAUNCH ESCAPE SYSTEM		2748	-56		2748	-56		
STRUCTURE		260			260			
ENGINE THRUST STRUCTURE		173	-42		173	-42	L=30 FT, A=4.0 IN2 + 20% ALUMINUM	
STABILIZING STRUTS, FTGS, ETC		87	-42		87	-42	ESTIMATE	
PROPULSION - LIQUID LES		2058			2058			
TURBOPUMP ASSEMBLY	1	1140	-66	1	1140	-66		
ENGINE	1	250	-88	1	250	-88		
ENGINE / TURBOPUMP MOUNT	1	20	-60	1	20	-60		
GAS GENERATOR	1	200	-60	1	200	-60		
GAS GENERATOR TANKAGE (WET)	1	160	-60	1	160	-60		
LO2 SYSTEM - DISCONNECT	1	12	-33	1	12	-33	DIA=5.0 IN	
LO2 SYSTEM - VALVE	1	20	-48	1	20	-48	DIA=5.0 IN	
LO2 SYSTEM - MANIFOLD	1	23	-53	1	23	-53	DIA = 5.0 IN, L=4 FT @ 5.7 LB/FT ALUMINUM	
RP SYSTEM - DISCONNECT	1	12	-33	1	12	-33	DIA=5.0 IN	
RP SYSTEM - VALVE	1	20	-48	1	20	-48	DIA=5.0 IN	
RP SYSTEM - MANIFOLD	1	14	-53	1	14	-53	DIA = 5.0 IN, L=4 FT @ 3.5 LB/FT ALUMINUM	
EQUIPMENT SUPPORT/INSTL		187			187		10 % OF EQUIPMENT	
POWER - WIRE HARNESS		40	-42		40	-42	SCALED FROM APOLLO	
OTHER - SEPARATION BOLTS	4	32	0	4	32	0		
WEIGHT GROWTH MARGIN		358	-45		358	-45	15 % OF HARDWARE	
TOTAL LAUNCH WEIGHT		39523	115		43733	128		
SEQUENCED MASS DATA								
TOTAL WEIGHT		39523	115		43733	128		
SEPARATE FROM LAUNCH VEH ADAPTER		-1956	-79		-1956	-79		
ON-PAD ABORT WEIGHT		37567	125		41777	137		
ON-ORBIT WEIGHT		32119	125		36330	139		
DELETE CONSUMABLES TO REENTRY		-62	146		-74	164		
DELETE POWER FLUIDS TO REENTRY		-326	70		-616	193		
DELETE NOMINAL RCS ON-ORBIT PROP		-303	240		-867	240		
DELETE ALL PROX OPS COLD GAS		-417	250		-916	270		
DELETE ALL OMS ON-ORBIT PROP		-3793	39		-4786	39		
SEPARATE PROX-OPS TANKS		-554	244		-1070	258		
SEPARATE SERVICE MODULE		0	0		-1620	312		
SEPARATE OMS POD		-4119	34		-4119	34		
BEGIN REENTRY WEIGHT		22546	150		22262	151		
DELETE CONSUMABLES		-19	146		-20	164		
DELETE REENTRY POWER FLUIDS		-12	70		-13	193		
DELETE NOMINAL RCS REENTRY PROP		-104	240		-103	240		
DEPLOY PARACHUTES		-844	200		-844	200		
LANDING WEIGHT		21567	148		21282	148		

Consumables - The number of personnel for the servicing mission is four, compared to ten for the crew rotation mission. The satellite servicing mission requires 363 lbm additional fuel cell reactants, 541 lbm extra RCS propellant, 498 lbm extra N_2 proximity operations propellant, and 993 lbm extra OMS propellant. The RCS and OMS tanks are sized for the larger service mission propellant loads and do not change, but extra proximity operations tanks and fuel cell reactant tanks are added for the service mission.

The total on-orbit weight of the system is 4211 lbm greater for the satellite servicing mission than for the crew rotation mission, however, servicing mission reentry weight is actually 284 lbm less due to the smaller crew size and jettisoned airlock.

The PLS reference coordinate system assumed for the mass properties analysis is shown in Figure 8.2-3. Station 0 is the crew module nose cap at the centerline of the vehicle. The PLS crew module is 238 inches long from nose cap to body flap hinge line with a maximum diameter of 168 inches.

A summary of the PLS sequential mass properties for the crew rotation mission is given in Table 8.2-4, with the center of mass based on the reference coordinate system and moments of inertia reported about the center of mass. Detailed mass properties for the crew rotation mission are given in Table 8.2-5.

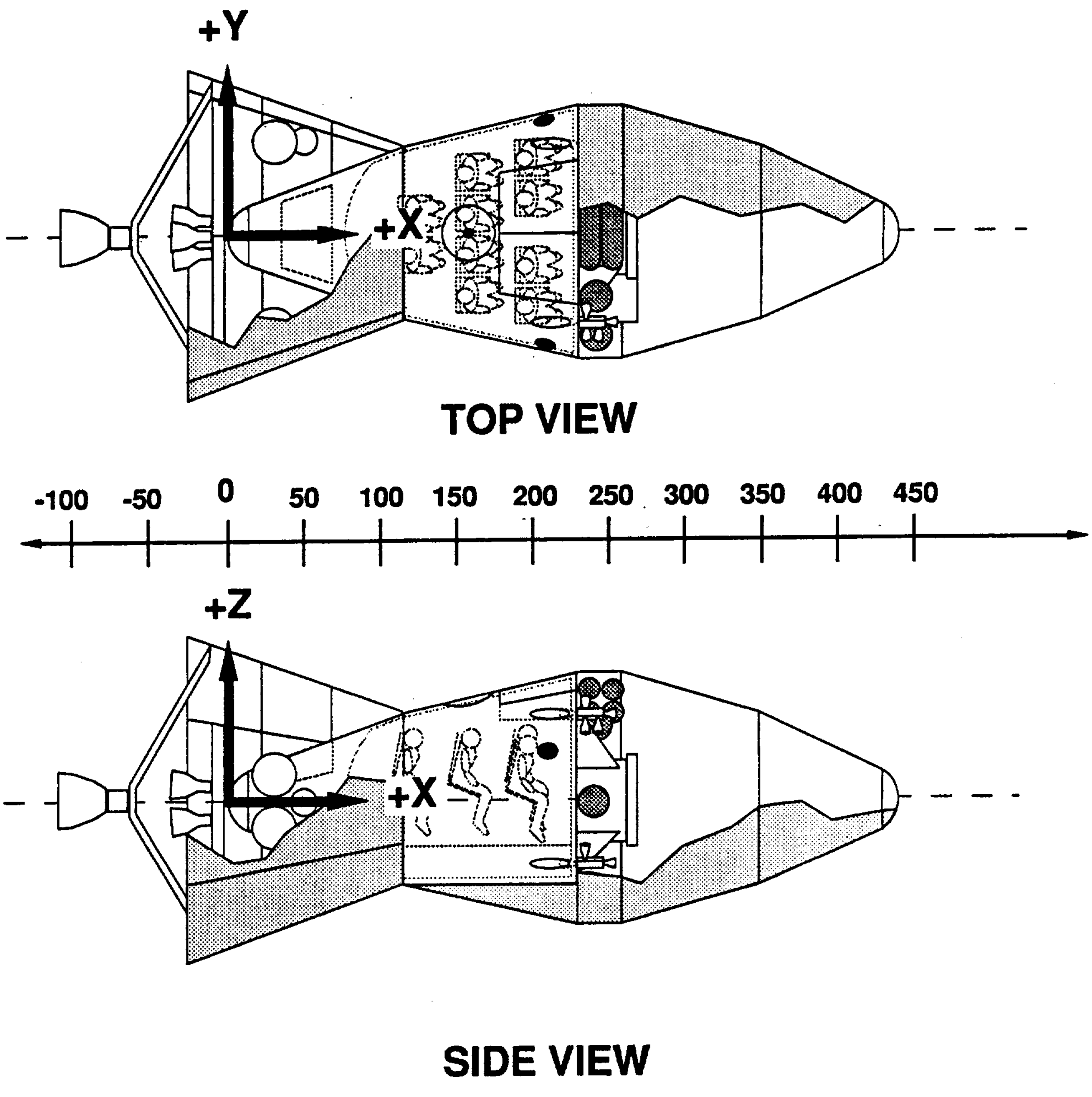


Figure 8.2-3 PLS Reference Coordinate System

Table 8.2-4 Sequential Mass Properties for PLS Crew Mission

SEQUENTIAL MASS PROPERTIES	PERSONNEL LAUNCH SYSTEM
FLATTENED BICONIC (10 PERSONNEL SIZE)	

WBS	T2	T3	T4	ITEM	WEIGHTS - LB		CENTER OF MASS - IN			MOMENTS (SLUG-FT2)		
					W3	W2	Xcg	Ycg	Zcg	IXX	IYY	IZZ
				CREW MODULE DRY WEIGHT		**19190**	**150**	**0**	**6**	**9.625E+03**	**2.619E+04**	**2.509E+04**
				CREW, RCS RESIDUALS, RESERVES		3582	174	13	9	1.470E+03	1.814E+03	2.594E+03
				NON- PROPELLANT CONSUMABLES		873	109	0	-7	2.158E+02	6.663E+02	5.941E+02
				RCS PROPELLANT - NOMINAL		563	243	0	-29	1.861E+02	5.272E+01	1.496E+02
				SATELLITE SERVICE MODULE		0	0	0	0	0.000E+00	0.000E+00	0.000E+00
				OMS / RADIATOR MODULE		4119	34	0	5	5.289E+03	4.337E+03	4.172E+03
				OMS PROPELLANTS - TOTAL		3793	35	0	0	2.395E+03	1.296E+03	1.296E+03
				ON-ORBIT WEIGHT		**32120**	**125**	**1**	**4**	**1.950E+04**	**5.460E+04**	**5.407E+04**
				LAUNCH VEHICLE ADAPTER		1956	-79	0	0	9.499E+03	4.744E+03	4.744E+03
				FORWARD FAIRING		2700	312	0	-3	2.214E+03	4.268E+03	4.154E+03
				BALLAST		0	0	0	0	0.000E+00	0.000E+00	0.000E+00
				EXPENDABLE LAUNCH ESCAPE SYSTEM		2748	-60	-7	1	1.175E+02	1.666E+02	2.398E+02
				TOTAL LAUNCH WEIGHT		**39523**	**114**	**1**	**3**	**3.141E+04**	**1.212E+05**	**1.206E+05**
				SEPARATE FROM LAUNCH VEHICLE ADAPTER		-1956	-79	0	0	-9.499E+03	-4.744E+03	-4.744E+03
				ON-PAD ABORT WEIGHT		**37567**	**125**	**1**	**4**	**2.190E+04**	**9.979E+04**	**9.922E+04**
				ON-ORBIT WEIGHT		**32120**	**125**	**1**	**4**	**1.950E+04**	**5.460E+04**	**5.407E+04**
				DELETE CONSUMABLES TO RENDEZVOUS		-31	146	0	-23	-3.005E+00	-1.771E+01	-1.489E+01
				DELETE POWER FLUIDS TO RENDEZVOUS		-82	70	0	11	-2.250E+01	-1.596E+01	-2.088E+01
				DELETE OMS CIRCULARIZATION PROPELLANT		-2382	39	0	0	-1.613E+03	-8.228E+02	-8.228E+02
				DELETE NOMINAL RCS TRIM PROP		-157	240	0	-40	-3.046E+01	-1.658E+00	-3.046E+01
				DELETE NOM COLD GAS RENDEZVOUS PROP		-78	250	0	0	-3.404E+01	-3.535E+00	-3.404E+01
				SSF RENDEVOUS WEIGHT		**29390**	**131**	**1**	**5**	**1.771E+04**	**4.888E+04**	**4.837E+04**
				DELETE CONSUMABLES TO REENTRY		-31	146	0	-23	-3.005E+00	-1.771E+01	-1.489E+01
				DELETE POWER FLUIDS TO REENTRY		-244	70	0	11	-6.686E+01	-4.741E+01	-6.204E+01
				DELETE OMS CIRCULARIZATION PROPELLANT		-1410	39	0	0	-9.547E+02	-4.871E+02	-4.871E+02
				DELETE NOMINAL RCS TRIM PROP		-151	240	0	-40	-2.927E+01	-1.594E+00	-2.927E+01
				DELETE ALL COLD GAS		-339	250	0	0	-1.481E+02	-1.538E+01	-1.481E+02
				SEPARATE PROX-OPS TANKS		-554	244	0	23	-2.887E+02	-9.861E+01	-2.284E+02
				SEPARATE SERVICE MODULE - AIRLOCK		0	0	0	0	0.000E+00	0.000E+00	0.000E+00
				SEPARATE OMS / RADIATOR MODULE		-4119	34	0	5	-5.289E+03	-4.337E+03	-4.172E+03
				BEGIN REENTRY WEIGHT		**22542**	**149**	**2**	**5**	**1.081E+04**	**2.800E+04**	**2.747E+04**
				DELETE REENTRY CONSUMABLES		-19	146	0	-23	-1.842E+00	-1.085E+01	-9.128E+00
				DELETE REENTRY POWER FLUIDS		-12	70	0	11	-3.333E+00	-2.364E+00	-3.094E+00
				DELETE NOMINAL RCS TRIM PROP		-100	240	0	-40	-1.938E+01	-1.055E+00	-1.938E+01
				DEPLOY PARACHUTES		-844	200	0	60	-9.637E+01	-3.571E+01	-9.637E+01
				LANDING WEIGHT		**21567**	**147**	**2**	**3**	**1.007E+04**	**2.665E+04**	**2.666E+04**

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 1 of 12)

SEMI-DETAILED MASS PROPERTIES — **PERSONNEL LAUNCH SYSTEM**
FLATTENED BICONIC (10 personnel - crew rotation mission)

ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
STRUCTURE - BODY GROUP				**5116**	**171**	**0**	**2**	**54.38**	**79.11**	**78.01**
FWD BODY			996		68	0	0	39.44	43.67	39.60
BODY STRUCTURE	1	609			80	0	0	42.70	41.40	41.40
LANDING GEAR WELL & FRAMES		142			40	0	-25	8.00	17.50	16.00
LANDING GEAR DOOR	1	59			40	0	-35	6.00	17.00	16.00
ACCESS PANELS	2	96			50	0	30	23.00	20.20	30.00
LAUNCH/PROP MODULE UMBIL PLATE	1	30			115	0	58	5.00	5.00	5.00
EQUIPMENT SUPPORT RACKS		60			50	0	15	15.50	23.00	17.00
MID/AFT BODY			1365		187	0	11	65.71	59.20	57.44
BODY STRUCTURE		1093			180	0	10	64.00	56.32	56.32
FTGS, CABIN ATTACHMENT	22	33			175	0	10	64.00	56.32	56.32
WINDOW, THERMAL	2	19			210	0	30	84.00	3.00	84.00
PARACHUTE COVER PANELS	2	88			200	0	80	24.00	13.00	27.00
SERVICE MODULE UMBILICAL PLATE	1	20			260	0	-30	3.00	3.00	3.00
RMS GRAPPLE FITTING	2	44			235	0	0	75.00	2.00	75.00
BODY FLAP CLOSEOUT/HINGE SUPT	1	68			230	0	-57	32.00	2.00	32.00
PRESSURIZED CABIN			2476		195	0	4	50.54	64.44	65.77
BULKHEAD, FWD	1	60			110	0	0	40.00	28.50	28.50
BULKHEAD, STA 226	1	330			226	0	5	50.00	40.00	40.00
GUSSETS, AFT BULKHEAD	4	60			240	0	5	49.00	35.00	35.00
BODY STRUCTURE, CABIN		794			173	0	10	60.00	52.00	52.00
BODY STRUCTURE, TUNNEL		99			248	0	0	25.00	20.40	20.40
PARTITION, STA 100	1	75			100	0	5	50.00	40.00	40.00
EQUIPMENT SUPPORT RACKS		150			95	0	0	49.00	35.00	35.00
FLOORING, EQUIP SUPT		184			173	0	-30	42.00	35.00	48.00
FTGS, CABIN ATTACHMENT	22	33			173	0	10	64.00	56.32	56.32
LATERAL WINDOWS	2	64			210	0	35	84.00	3.00	84.00
AFT WINDOWS	2	64			226	0	35	50.00	5.00	50.00
DOCKING ADAPTER MECHANISM	1	340			263	0	0	30.00	21.00	21.00
AIRLOCK INTERFACE RING	0	0			0	0	0	30.00	21.00	21.00
TOP HATCH	1	90			150	0	0	12.50	17.70	17.70
DOCKING HATCH	1	133			260	0	0	12.50	17.70	17.70
BODY FLAP	1		279		250	0	-55	35.00	12.00	36.10

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 2 of 12)

SEMI-DETAILED MASS PROPERTIES — **PERSONNEL LAUNCH SYSTEM**
FLATTENED BICONIC (10 personnel - crew rotation mission)

WBS	T2 T3 T4 ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
	PROTECTION				**1221**	**119**	**0**	**-9**	**49.87**	**83.10**	**84.32**
	EXTERNAL TPS			919		113	0	-13	46.11	84.70	86.57
	NOSE CAP, PANELS (ZONE 1)		157			12	0	0	17.00	14.00	14.00
	BODY TPS, ZONE 2		178			75	0	-30	17.00	32.00	36.00
	BODY TPS, ZONE 3		399			140	0	-28	49.00	71.00	80.00
	BODY TPS, ZONE 4		111			140	0	35	49.00	71.00	80.00
	AFT BULKHEAD TPS, ZONE 5		74			230	0	5	50.00	40.00	40.00
	INTERNAL INSULATION / TCS			220		151	0	5	59.73	68.13	68.06
	INSULATION - FWD BODY		52			75	0	0	42.70	41.40	41.40
	INSULATION - CABIN		168			175	0	7	64.00	56.32	56.32
	PURGE AND VENT SYSTEM			63		75	0	0	40.00	40.00	40.00
	WINDOW / HATCH CONDITIONING			19		220	0	35	70.00	40.00	70.00
	PROPULSION - REACTION CONTROL				**972**	**241**	**0**	**10**	**54.87**	**36.68**	**43.22**
	THRUSTER MODULES			196		235	0	9	69.82	47.98	52.27
	THRUSTERS - RCS	16	133			235	0	14	80.00	55.00	60.00
	THRUSTERS - COLD GAS	12	45			235	0	14	30.00	5.00	30.00
	THRUSTER MODULE SUPPORT	4	18			235	0	-40	30.00	1.00	30.00
	PRESSURIZATION SYSTEM			66		240	0	-8	53.87	31.93	44.81
	GN2 BOTTLE(S) - RCS	7	28			240	0	-32	45.00	14.50	45.00
	REGULATORS	14	9			240	0	32	45.00	14.50	45.00
	FILL & DRAIN DISCONNECTS	1	1			240	0	-45	0.00	0.00	0.00
	MANIFOLD/PLUMBING		10			240	0	14	65.00	46.00	46.00
	TANK VENT / RELIEF		9			240	0	0	45.00	5.00	45.00
	PRESS SYS SUPPORT		9			240	0	0	45.00	5.00	45.00
	PROPELLANT SUPPLY - RCS			193		240	0	-13	44.16	29.92	32.86
	TANKAGE - H2O2	2	60			240	0	-40	30.00	7.00	30.00
	TANKAGE - RP	1	15			240	0	-40	30.00	1.00	30.00
	VALVES	9	35			240	0	14	65.00	46.00	46.00
	MANIFOLD/PLUMBING	1	40			240	0	0	0.00	0.00	0.00
	TANK FILL, VENT & DRAIN	2	25			240	0	0	45.00	5.00	45.00
	PROPELLANT SUPPLY SUPPORT		18			240	0	0	30.00	7.00	30.00
	PROPELLANT SUPPLY - PROX OPS (fixed)			36		245	0	0	30.00	2.00	15.00
	FLIGHT DISCONNECTS	1	1			245	0	0	30.00	2.00	15.00
	MANIFOLD/PLUMBING		32			245	0	0	30.00	2.00	15.00
	COLD GAS SUPPLY SUPPORT		3			245	0	0	30.00	2.00	15.00
	PROPELLANT SUPPLY - PROX-OPS (expend)			481		244	0	23	49.15	28.73	43.72
	N2 BOTTLE(S) - COLD GAS	4	310			250	0	32	45.00	14.50	45.00
	VALVES	16	82			230	0	32	45.00	5.00	45.00
	FLIGHT DISCONNECT	1	1			230	0	32	45.00	5.00	45.00
	FILL / DRAIN DISCONNECT	4	4			250	0	-45	0.00	0.00	0.00
	MANIFOLD/PLUMBING		10			230	0	14	65.00	46.00	46.00
	TANK VENT / RELIEF		14			250	0	0	45.00	5.00	45.00
	TANK SEPARATION	4	16			230	0	32	45.00	14.50	45.00
	COLD GAS SUPPLY SUPPORT		44			230	0	-45	0.00	0.00	0.00

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 3 of 12)

SEMI-DETAILED MASS PROPERTIES — **PERSONNEL LAUNCH SYSTEM**
FLATTENED BICONIC (10 personnel - crew rotation mission)

WBS	T2	T3	T4	ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
				POWER - ELECTRICAL				**2157**	**63**	**0**	**-1**	**27.46**	**41.55**	**41.38**
				POWER SUPPLY			1300		46	0	-4	18.91	23.75	24.20
				FUEL CELLS	2	361			45	0	-15	15.00	10.00	15.00
				BATTERIES	6	432			25	0	0	10.00	10.00	10.00
				O2 TANKAGE (EPS & ECLSS)	2	90			70	0	15	35.00	29.00	35.00
				H2 TANKAGE	2	94			70	0	-15	35.00	29.00	35.00
				REACTANT PLUMBING	4	108			70	0	0	10.00	5.00	10.00
				COOLANT PLUMBING		45			55	0	0	10.00	5.00	10.00
				POWER SUPPLY SUPT/INSTL		170			60	0	0	0.00	0.00	0.00
				POWER DIST EQUIP			169		78	0	15	5.00	42.90	42.90
				POWER DISTRIBUTION PANELS	3	99			45	0	15	5.00	5.00	5.00
				10VDC POWER SUPPLY	3	1			45	0	15	5.00	5.00	5.00
				LIGHTS		35			150	0	15	5.00	5.00	5.00
				POWER DISTRIBUTION SUPT/INSTL		34			100	0	15	5.00	5.00	5.00
				WIRING			688		90	0	0	40.00	50.00	50.00
				SURFACE CONTROLS				**121**	**240**	**0**	**-45**	**7.00**	**10.00**	**7.00**
				BODY FLAP ACTUATION			121		240	0	-45	7.00	10.00	7.00
				AVIONICS				**1637**	**129**	**0**	**10**	**27.11**	**61.65**	**59.68**
				GUIDANCE, NAVIGATION AND CONTROL			229		142	0	1	35.12	69.04	73.60
				FAULT-TOLERANT NAVIGATOR	1	50			95	0	10	12.00	17.00	17.00
				GPS RECEIVER	2	12			95	0	10	12.00	17.00	17.00
				GPS ANTENNAS	2	10			240	0	0	80.00	2.00	80.00
				HORIZON SCANNER	2	12			240	0	0	80.00	2.00	80.00
				RADAR ALTIMETER	2	10			240	0	0	80.00	2.00	80.00
				BODY FLAP DRIVER	1	45			230	0	-30	2.00	2.00	2.00
				RCS/ OMS VALVE DRIVER	2	90			95	0	10	12.00	17.00	17.00
				RENDEVOUS AND DOCK			133		217	-1	-16	26.26	23.47	27.78
				RENDEVOUS RADAR	1	30			235	30	0	5.00	5.00	5.00
				RADAR SIGNAL PROCESSOR	1	70			200	0	-30	5.00	5.00	5.00
				ANTENNA	1	8			235	-30	0	5.00	5.00	5.00
				ANTENNA MAST, DEPLOYMENT MECHS	1	25			235	-30	0	10.00	2.00	10.00
				VEHICLE HEALTH MONITORING			75		90	0	0	30.00	20.00	20.00
				MASS MEMORY	3	75			90	0	0	30.00	20.00	20.00

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 4 of 12)

SEMI-DETAILED MASS PROPERTIES	PERSONNEL LAUNCH SYSTEM
FLATTENED BICONIC (10 personnel - crew rotation mission)	

WBS	T2	T3	T4 ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
			COMMUNICATIONS AND TRACKING			238		95	0	10	12.00	17.00	17.00
			CENTRAL DATA FORMATTER	1	27								
			TRANSPONDER	1	16								
			POWER AMP	1	18								
			DIPLEXER, RF SWITCH	1	3								
			AUDIO	1	40								
			UHF TRANSCEIVER	1	20								
			ANTENNAS	3	24								
			SEARCH AND RESCUE RADIO	1	40								
			SIGNAL CABLING		50								
			CONTROLS AND DISPLAYS			185		210	0	50	19.00	12.00	14.00
			RECONFIG DISPLAYS / CONTROL UNITS	5	50								
			ELECTRONIC INTERFACES	3	75								
			RECONFIG. PUSH-BUTTON PANEL	3	30								
			RMS WORKSTATION	0	0								
			HAND CONTROLLERS	2	30								
			INSTRUMENTATION			83		40	0	10	12.00	17.00	17.00
			SENSOR INTERFACE UNIT (SIU)	60	30								
			NETWORK INTERFACE UNIT (NIU)	2	3								
			SENSORS, INSTRUMENTATION	700	50								
			DATA HANDLING			463		95	0	10	12.00	17.00	17.00
			FAULT TOLERANT PROCESSOR	3	99								
			MASS MEMORY	3	75								
			DATA BUS COUPLERS	60	30								
			MDM	7	259								
			STRUCTURES/MECHS CONTROLS			82		173	0	-27	22.72	51.51	48.66
			CHUTE, LANDING GEAR CONTROLLER	1	61			200	0	-40	2.00	2.00	2.00
			LASER FIRING UNIT	2	20			95	0	10	12.00	17.00	17.00
			LASER INITIATORS	5	1			95	0	10	12.00	17.00	17.00
			AVIONICS SUPT/INSTL			149		134	0	20	0.00	0.00	0.00

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 5 of 12)

SEMI-DETAILED MASS PROPERTIES — PERSONNEL LAUNCH SYSTEM
FLATTENED BICONIC (10 personnel - crew rotation mission)

WBS	T2	T3	T4	ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
				ENVIRONMENTAL CONTROL				1406	104	0	-12	33.42	45.15	38.58
				CABIN AND PERSONNEL SYSTEM			416		137	0	-40	8.59	39.93	39.93
				O2 TANKAGE - CRYO STORAGE	0	0			200	0	-40	0.00	0.00	0.00
				O2 TANKAGE - (GAS FOR REPRESS)	1	15			200	0	-40	5.00	5.00	5.00
				N2 TANKAGE - (GAS FOR REPRESS)	4	60			200	0	-40	5.00	5.00	5.00
				PRESS PLUMBING		12			190	0	-40	20.00	20.00	20.00
				CABIN PRESS & COMPOSITION CNTRLS		65			170	0	-40	5.00	5.00	5.00
				CO2 REMOVAL - 2-BED LIOH		11			130	0	-40	10.00	10.00	10.00
				LIOH CANISTER STORAGE		100			100	0	-40	10.00	10.00	10.00
				TEMP AND HUMIDITY CONTROL		127			110	0	-40	5.00	5.00	5.00
				TRACE CONTAMINANT CONTROL		7			130	0	-40	5.00	5.00	5.00
				DUCTING, MISC		20			130	0	-40	20.00	20.00	20.00
				EQUIPMENT COOLING			209		95	0	0	40.00	28.00	28.00
				EQUIPMENT COLD PLATES		120			95					
				AVIONICS COOLING ASSY		28			95					
				IMU HEAT EXCHANGER ASSY	1	31			95					
				PLUMBING		20			95					
				DUCTING, MISC		10			95					
				HEAT TRANSFER WATER LOOP			161		100	0	-40	26.00	26.00	40.00
				HEAT EXCHANGER - POTABLE WATER	1	17			100	0	-40			
				PRIMARY, SECONDARY WATER PUMPS		78			100	0	-40			
				PLUMBING		30			100	0	-40			
				COOLANT IN LOOP - WATER		36			100	0	-40			
				HEAT TRANSFER FREON LOOP			270		82	0	20	4.00	17.93	17.93
				HEAT EXCHANGER - WATER-FREON	1	50			90	0	20	4.00	4.00	4.00
				HEAT EXCHANGER - GSE	1	50			90	0	20	4.00	4.00	4.00
				HEAT EXCHANGER - FUEL CELL	1	50			45	0	20	4.00	4.00	4.00
				FREON PUMP PACKAGE	2	90			90	0	20	4.00	4.00	4.00
				COOLANT IN LOOP - FREON		30			90	0	20	4.00	4.00	4.00
				HEAT REJECTION			222		82	0	15	27.66	29.92	29.92
				AMMONIA BOILER ASSEMBLY		45			40	0	15	4.00	4.00	4.00
				COOLANT TANKAGE - WATER		14			90	0	15	4.00	4.00	4.00
				FLASH EVAPORATOR - WATER		58			80	0	15	4.00	4.00	4.00
				TOPPING DUCT ASSEMBLY		78			100	0	15	40.00	28.00	28.00
				HIGH LOAD DUCT ASSEMBLY		27			100	0	15	40.00	28.00	28.00
				RADIATOR PANELS			0			0	30	23.00	20.20	30.00
				ECLSS SUPT/INSTL			128		104	0	-16	0.00	0.00	0.00

BOEING

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 6 of 12)

SEMI-DETAILED MASS PROPERTIES — PERSONNEL LAUNCH SYSTEM
FLATTENED BICONIC (10 personnel - crew rotation mission)

WBS	T2	T3	T4 ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
			OTHER - PERSONNELPROVISIONS				1535	150	-2	-2	35.42	34.30	44.10
			FOOD MANAGEMENT			117		150	0	0	50.00	20.00	50.00
			GALLEY		0			130	-50	0	22.00	22.00	10.00
			FOOD STORAGE UNITS		117			150	0	0	50.00	20.00	50.00
			WATER MANAGEMENT			85		100	21	-21	35.37	25.40	30.89
			WATER STORAGE TANK		50			100	0	-35	24.00	24.00	24.00
			HANDWASH - WET WIPES		2			100	50	0	0.00	0.00	0.00
			WATER DISPENSER		23			100	50	0	5.00	5.00	5.00
			PLUMBING, VALVES, ETC		10			100	50	0	5.00	5.00	5.00
			WASTE MANAGEMENT			80		115	-50	0	20.00	20.00	20.00
			WASTE WATER TANK		50			115	-50	0	20.00	20.00	20.00
			COMMODE SYSTEM		15			115	-50	0	20.00	20.00	20.00
			EMERGENCY WASTE COLLECTION		15			115	-50	0	20.00	20.00	20.00
			FIRE DETECTION / SUPPRESSION			13		100	0	-35	10.00	10.00	10.00
			SMOKE DETECTORS		7			100	0	-35	10.00	10.00	10.00
			FIRE SUPPRESSION TANK		6			100	0	-35	10.00	10.00	10.00
			FURNISHINGS AND EQUIPMENT			1100		157	0	0	33.15	33.45	42.00
			SEATS, PERSONNEL RESTRAINTS	4	400			190	0	0	21.00	17.00	17.00
			SEATS, PERSONNEL RESTRAINTS	4	400			150	0	0	34.00	17.00	31.00
			SEATS, PERSONNEL RESTRAINTS	2	200			110	0	0	40.00	17.00	38.00
			INCIDENTAL EQUIPMENT	10	100			150	0	0	50.00	20.00	50.00
			SUPPORT/INSTALLATION			140		152	-7	-2	0.00	0.00	0.00

BOEING

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 7 of 12)

SEMI-DETAILED MASS PROPERTIES FLATTENED BICONIC (10 personnel - crew rotation mission)															
PERSONNEL LAUNCH SYSTEM															
						WEIGHTS - LB			CENTER OF MASS - IN			RADIUS OF GYRATION (IN)			
WBS	T2	T3	T4	ITEM	Qty	W4	W3	W2	Xcg	Ycg	Zcg	RXX	RYY	RZZ	
				OTHER - RECOVERY & AUXILIARY				2522	194	0	38	54.03	54.89	53.80	
				PARACHUTE SYSTEM			1726		200	0	60	23.00	14.00	23.00	
				DROGUE CHUTES	1	290			200						
				BACKUP DROGUE	1	290			200						
				MAIN CHUTE - HI-GLIDE	1	444			200						
				BACKUP CHUTES - HI-GLIDE	1	444			200						
				PARACHUTE CNTRL SPINDLE, MOTORS	2	100			200						
				PARACHUTE SUPT/INSTL		157			200						
				LANDING SYSTEM			606		187	0	-17	67.54	72.94	93.17	
				NOSE LANDING GEAR	1	108			40	0	-25	8.00	17.50	16.00	
				AFT LANDING GEAR	2	431			220	0	-15	75.00	26.00	70.00	
				FLOTATION COLLAR AIRBAGS	4	12			240	0	0	30.00	20.00	20.00	
				LANDING GEAR SUPT/INSTL		55			202	0	-17	75.00	26.00	70.00	
				SATELLITE SERVICE MODIFICATIONS			0		0	0	0				
				LARGE RMS	0	0			0	0	0				
				SMALL RMS	0	0			0	0	0				
				TOOLS, MISCELLANEOUS	0	0			0	0	0				
				EVA SUITS, WITH EXPENDABLES	0	0			0	0	0				
				SEPARATION			190		169	0	17	70.76	75.85	69.34	
				PARACHUTE COVERS SEPARATION	2	40			200	0	80	24.00	13.00	27.00	
				FWD FAIRING SEPARATION		60			230	0	0	84.00	59.00	59.00	
				LAUNCH VEHICLE SEP BOLTS	6	90			115	0	0	58.00	41.00	41.00	
				CREW MOD DRY, EXCL GROWTH				16687	150	0	6	48.20	79.52	77.83	
				WEIGHT GROWTH MARGIN				2503	150	0	6	48.20	79.52	77.83	
				CREW MODULE DRY WEIGHT				19190	150	0	6	48.20	79.52	77.83	
				MOMENT OF INERTIA - SL-FT2								9624.87	26192.85	25092.11	

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 8 of 12)

SEMI-DETAILED MASS PROPERTIES — **PERSONNEL LAUNCH SYSTEM**
FLATTENED BICONIC (10 personnel - crew rotation mission)

WBS	T2 T3 T4 ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
	NON- CARGO ITEMS				**3582**	**174**	**13**	**9**	**43.60**	**48.43**	**57.93**
1.1.17	FLIGHT CREW, WITH EQUIPMENT			3000		160	16	15	40.68	36.46	50.35
	PILOT	2	600			200	26	15	56.00	17.00	54.00
	PASSENGER	2	600			190	40	15	32.00	17.00	30.00
	PASSENGER	4	1200			150	13	15	33.00	17.00	30.00
	PASSENGER	2	600			110	-13	15	20.00	17.00	18.00
1.1.20	PROPELLANT RESIDUALS			103		241	0	-22	43.79	23.47	40.26
	RCS RESIDUAL BI-PROP		42			235	0	-40	30.00	7.00	30.00
	RCS N2 PRESSURANT		18			235	0	-32	45.00	14.50	45.00
	COLD GAS RESIDUALS		43			250	0	0	45.00	14.50	45.00
1.1.21	PROPELLANT RESERVES			479		245	0	-22	42.53	23.32	37.91
	RCS RESERVES - BIPROP		261			240	0	-40	30.00	7.00	30.00
	RCS RESERVES - COLD GAS		218			250	0	0	45.00	14.50	45.00
	CREW MODULE INERT WEIGHT				**22772**	**153**	**2**	**6**	**47.78**	**76.00**	**75.71**
	MOMENT OF INERTIA - SL-FT2								11219.97	28386.80	28176.59
	NON- PROPELLANT				**873**	**109**	**0**	**-7**	**33.85**	**59.47**	**56.16**
	IN-FLIGHT LOSSES			422		70	0	11	35.63	30.00	34.32
	FUEL CELL NOMINAL O2		300			70	0	15	35.00	29.00	35.00
	FUEL CELL NOMINAL H2		38			70	0	-15	35.00	29.00	35.00
	FUEL CELL O2 RESERVES		60			70	0	15	35.00	29.00	35.00
	FUEL CELL H2 RESERVES		8			70	0	-15	35.00	29.00	35.00
	FUEL CELL RESIDUAL REACTANT		16			70	0	0	0.00	0.00	0.00
	LIFE SUPPORT CONSUMABLES			451		146	0	-23	21.19	51.44	47.18
	O2 - CRYO STORAGE		35			70	0	15	0.00	0.00	0.00
	O2 - GAS FOR REPRESSURIZATION		14			200	0	-40	0.00	0.00	0.00
	O2 - CABIN PRESSURIZATION		14			200	0	-40	0.00	0.00	0.00
	N2 - GAS FOR REPRESS, LOSSES		67			200	0	-40	0.00	0.00	0.00
	N2 - CABIN PRESSURIZATION		63			200	0	-40	0.00	0.00	0.00
	FOOD		128			150	0	0	10.00	10.00	10.00
	POTABLE WATER		80			100	0	-35	0.00	0.00	0.00
	HYGIENE WATER		0			100	0	-35	0.00	0.00	0.00
	EQUIP COOLING FLUIDS		50			90	0	-40	0.00	0.00	0.00
	PROPELLANT - NOMINAL				**563**	**243**	**0**	**-29**	**39.13**	**20.83**	**35.09**
	RCS NOM PROPELLANT - BIPROP			407		240	0	-40	30.00	7.00	30.00
	RCS NOM PROPELLANT - COLD GAS			156		250	0	0	45.00	14.50	45.00
	OMS FLUIDS			0			0	0			
	GROSS WEIGHT, LESS OMS				**24208**	**154**	**2**	**5**	**47.51**	**76.55**	**76.10**
	MOMENT OF INERTIA - SL-FT2								11794.98	30615.50	30259.07

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 9 of 12)

SEMI-DETAILED MASS PROPERTIES — PERSONNEL LAUNCH SYSTEM
FLATTENED BICONIC (10 personnel - crew rotation mission)

WBS	T2 T3 T4 ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
	SATELLITE SERVICE MODULE				0	0					
	STRUCTURE			0							
	CREW MODULE INTERFACE RING	0	0								
	AIRLOCK MODULE, LESS HATCH	0	0								
	AIRLOCK HATCH, STRUCTURE	0	0								
	AIRLOCK HATCH, MECHANISM	0	0								
	TOOL, EQUIPMENT SUPPORT	0	0								
	CREW MODULE UMBILICAL PLATE	0	0								
	POWER - ELECTRICAL			0							
	O2 TANKAGE (EPS & ECLSS)	0	0								
	H2 TANKAGE	0	0								
	REACTANT FILL & DRAIN PLUMBING	0	0								
	REACTANT RELIEF, VENT PLUMBING	0	0								
	REACTANT SUPPLY PLUMBING	0	0								
	REACTANT SUPPLY VALVES, DISC	0	0								
	WIRE HARNESS, LIGHTING, ETC	0	0								
	POWER SUPPLY SUPT/INSTL		0								
	OTHER - SEPARATION			0							
	AIRLOCK SEPARATION	0	0								
	OTHER - AUXILIARY SYSTEMS			0							
	LARGE RMS	0	0								
	SMALL RMS	0	0								
	SPARES, SUPPORT EQUIPMENT	0	0								
	EVA SUITS, WITH EXPENDABLES	0	0								
	WEIGHT GROWTH MARGIN			0							

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 10 of 12)

SEMI-DETAILED MASS PROPERTIES	PERSONNEL LAUNCH SYSTEM
FLATTENED BICONIC (10 personnel - crew rotation mission)	

WBS	T2	T3	T4 ITEM	Qty	WEIGHTS - LB			CENTER OF MASS - IN			RADIUS OF GYRATION (IN)		
					W4	W3	W2	Xcg	Ycg	Zcg	RXX	RYY	RZZ
			PROPULSION / RADIATOR MODULE				**4119**	**34**	**0**	**5**	**77.13**	**69.84**	**68.50**
			STRUCTURE			1312		36	0	4	84.27	74.55	77.09
			AFT ADAPTER INTERFACE RING	1	158			-20	0	0	111.00	78.00	78.00
			CREW MODULE INTERFACE RING	1	92			115	0	0	58.00	41.00	41.00
			PRIMARY STRUCTURE		679			48	0	0	89.00	75.00	75.00
			LAUNCH / CREW MOD UMBIL PLATES	2	60			48	0	85	29.00	70.00	70.00
			THRUST STRUCTURE	1	177			-5	0	0	40.00	30.00	30.00
			TANK SUPPORT STRUTS		146			39	0	0	80.00	10.00	80.00
			THERMAL PROTECTION			71		50	0	0	85.00	60.00	60.00
			PROPULSION - OMS			1066		15	0	0	37.53	36.98	36.98
			ENGINES	3	150			-13	0	0	20.00	45.00	45.00
			ENGINE MOUNT	3	15			-3	0	0	20.00	14.00	14.00
			LO2 SYSTEM - TANK	2	93			39	0	0	56.00	40.00	40.00
			LO2 SYSTEM - VALVES	6	24			4	0	0	56.00	40.00	40.00
			LO2 SYSTEM - MANIFOLD	1	144			8	0	0	40.00	28.00	28.00
			LO2 SYSTEM - LES VALVES	1	20			-10	0	0	10.00	10.00	10.00
			LO2 SYSTEM - LES DISCONNECT	1	12			-30	0	0	10.00	10.00	10.00
			LO2 SYSTEM - FILL, DRAIN, VENT	1	24			39	0	0	28.00	20.00	20.00
			LO2 SYSTEM - SUPPORT, INSTL		48			39	0	0	0.00	0.00	0.00
			RP SYSTEM - TANK	2	115			39	0	0	56.00	40.00	40.00
			RP SYSTEM - VALVES	6	24			4	0	0	56.00	40.00	40.00
			RP SYSTEM - MANIFOLD	1	89			8	0	0	40.00	28.00	28.00
			RP SYSTEM - LES VALVES	1	20			-10	0	0	10.00	10.00	10.00
			RP SYSTEM - LES DISCONNECT	1	12			-30	0	0	10.00	10.00	10.00
			RP SYSTEM - FILL, DRAIN, VENT	1	24			39	0	0	28.00	20.00	20.00
			RP SYSTEM - SUPPORT, INSTL		43			39	0	0	0.00	0.00	0.00
			GN2 BOTTLES - OMS	2	128			22	0	0	28.00	20.00	20.00
			GAS VALVES	4	18			8	0	0	56.00	40.00	40.00
			REGULATORS	2	9			8	0	0	56.00	40.00	40.00
			FILL & DRAIN DISCONNECTS	2	2			22	0	0	28.00	20.00	20.00
			MANIFOLD/PLUMBING		10			8	0	0	40.00	28.00	28.00
			BOTTLE VENT / RELIEF		17			22	0	0	28.00	20.00	20.00
			PRESS SYSTEM SUPPORT		25			8	0	0	0.00	0.00	0.00
			POWER DISTRIBUTION			188		48	0	85	15.00	41.00	41.00
			WIRING, INCL GROUND UMBILICALS		150								
			EQUIPMENT SUPPORT/INSTL		38								
			ECLSS RADIATOR PANELS			795		50	0	0	89.00	75.00	75.00
			COOLANT IN PANELS - FREON		30								
			FIXED PANELS	2	304								
			DEPLOYED PANELS	2	461								
			OTHER - AUXILIARY SYSTEMS			150		30	0	0	93.48	95.36	95.36
			LAUNCH VEHICLE SEPARATION	6	90			-26	0	0	111.00	78.00	78.00
			CREW MODULE SEPARATION	6	60			115	0	0	58.00	41.00	41.00
			WEIGHT GROWTH MARGIN			537		35	0	0	89.00	75.00	75.00

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 11 of 12)

SEMI-DETAILED MASS PROPERTIES — **PERSONNEL LAUNCH SYSTEM**
FLATTENED BICONIC (10 personnel - crew rotation mission)

WBS	T2	T3	T4	ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
				OMS PROPELLANTS				**3793**	**35**	**0**	**0**	**54.09**	**39.78**	**39.78**
				OMS RESIDUALS			549		14	0	0	41.03	30.89	30.89
				RESIDUALS - IN TANKS		73			39	0	0	56.00	40.00	40.00
				RESIDUALS - IN LINES, ENGINES		395			8	0	0	40.00	28.00	28.00
				PRESSURANTS		81			22	0	0	28.00	20.00	20.00
				OMS RESERVES			295		39	0	0	56.00	40.00	40.00
				RESERVE PROPELLANT		295			39	0	0	56.00	40.00	40.00
				OMS NOMINAL PROPELLANT			2949		39	0	0	56.00	40.00	40.00
				ON-ORBIT GROSS WEIGHT				**32120**	**125**	**1**	**4**	**53.04**	**88.74**	**88.31**
				MOMENT OF INERTIA - SL-FT2								19500.65	54600.57	54066.10
				LAUNCH VEHICLE ADAPTER				**1956**	**-79**	0	0	150.00	106.00	106.00
				STRUCTURE			1363		-79	0	0	150.00	106.00	106.00
				PROTECTION - THERMAL			0		-79	0	0	150.00	106.00	106.00
				POWER - WIRE HARNESS			188		-79	0	0	150.00	106.00	106.00
				OTHER - CREW MOD SEPARATION SYS	6		150		-79	0	0	150.00	106.00	106.00
				WEIGHT GROWTH MARGIN			255		-79	0	0	150.00	106.00	106.00
				FORWARD FAIRING				**2700**	**312**	0	-3	61.63	85.58	84.43
				STRUCTURE			1747		317	0	-5	67.33	90.36	88.71
				FAIRING NOSE CAP		45			504	0	0	10.00	7.00	7.00
				FAIRING - CONIC SECTION		1148			348	0	0	60.00	70.00	70.00
				FAIRING - CYLINDRICAL SECTION		444			250	0	0	84.00	60.00	60.00
				FAIRING - FLAT SECTION COVER		110			192	0	-75	25.00	25.00	35.00
				PROTECTION - THERMAL			239		348	0	0	0.00	0.00	0.00
				OTHER - AUXILIARY SYS			362		230	0	0	54.00	38.00	38.00
				SEPARATION JOINTS		212			230	0	0	54.00	38.00	38.00
				SEPARATION SPRINGS/FTGS		150			230	0	0	54.00	38.00	38.00
				WEIGHT GROWTH MARGIN			352		348	0	0	60.00	70.00	70.00
				BALLAST				**0**	**0**					
				FWD NOSE BALLAST			0		504	0	0	8.00	8.00	8.00

Table 8.2-5 Detailed Mass Properties for Crew Rotation Mission (Page 12 of 12)

SEMI-DETAILED MASS PROPERTIES — **PERSONNEL LAUNCH SYSTEM**
FLATTENED BICONIC (10 personnel - crew rotation mission)

WBS	T2	T3	T4	ITEM	Qty	WEIGHTS - LB W4	W3	W2	CENTER OF MASS - IN Xcg	Ycg	Zcg	RADIUS OF GYRATION (IN) RXX	RYY	RZZ
				EXPENDABLE LAUNCH ESCAPE SYSTEM				**2748**	**-60**	**-7**	**1**	**14.08**	**16.76**	**20.11**
				STRUCTURE			260		-42	0	0	6.27	6.27	6.27
				ENGINE THRUST STRUCTURE		173			-42	0	0	3.00	3.00	3.00
				STABILIZING STRUTS, FTGS, ETC		87			-42	0	0	10.00	10.00	10.00
				PROPULSION - LIQUID LES			2058		-66	-9	2	15.40	13.74	18.23
				TURBOPUMP ASSEMBLY	1	1140			-66	-20	0	3.00	3.00	3.00
				ENGINE	1	250			-88	0	0	10.00	20.00	20.00
				ENGINE / TURBOPUMP MOUNT	1	20			-60	-20	0	3.00	3.00	3.00
				GAS GENERATOR	1	200			-60	20	0	3.00	3.00	3.00
				GAS GENERATOR TANKAGE (WET)	1	160			-60	0	20	10.00	10.00	10.00
				LO2 SYSTEM - DISCONNECT	1	12			-33	0	-10	2.00	2.00	2.00
				LO2 SYSTEM - VALVE	1	20			-48	0	-10	2.00	2.00	2.00
				LO2 SYSTEM - MANIFOLD	1	23			-53	0	-10	3.00	10.00	10.00
				RP SYSTEM - DISCONNECT	1	12			-33	0	10	2.00	2.00	2.00
				RP SYSTEM - VALVE	1	20			-48	0	10	2.00	2.00	2.00
				RP SYSTEM - MANIFOLD	1	14			-53	0	10	3.00	10.00	10.00
				EQUIPMENT SUPPORT/INSTL		187			-60	0	0	0.00	0.00	0.00
				POWER - WIRE HARNESS			40		-42	0	0	1.00	10.00	10.00
				OTHER - SEPARATION BOLTS	4		32		0	0	0	0.00	0.00	0.00
				WEIGHT GROWTH MARGIN			358		-45	0	0	0.00	0.00	0.00
				TOTAL LAUNCH WEIGHT				**39523**	**114**	**1**	**3**	**60.68**	**119.18**	**118.90**
				MOMENT OF INERTIA - SL-FT2								31407.35	121170.85	120596.28

9 SUBSYSTEM TRADE STUDIES AND DEFINITION

The following sections describe the PLS subsystems in the order that they are shown in a mass properties statement.

9.1 Structures and Mechanisms

The structural loads encountered for both ascent and descent spacecraft are well understood. Previous hardware experience should be adequate for a PLS. In general, though, applying the "lessons learned" from the aircraft world that result in superior operability will include adopting techniques such as overdesign, design for robustness, and design for manufacturability. In the past, spacecraft system designs have tended to be performance driven; the extra weight penalties for stouter structure/mechanisms were not permissible. This quest for performance occasionally led to the use of exotic materials or manufacturing processes that are inconsistent with the minimum LCC, and in some cases result in environmental hazards during or as a result of manufacture that are no longer acceptable. Unless the PLS is required to use a launch vehicle with marginal performance capability, design of the PLS structure and mechanisms with safety, operability, and manufacturability (cost) as the key requirements, instead of weight, would be desirable.

9.1.1 Structure

As is the case with any reentry vehicle, any discussion of the primary structure must consider the Thermal Protection System (TPS) concept and vice versa (see Section 9.2). Given the near term technology availability date (TAD) of 1992 for this study, proven "cold" structural technology, based on aluminum, was selected in combination with an overlayed TPS.

The PLS design consists of several elements:

- a primary external "shell" shaped as a scarfed biconic,
- a pressurized cab for personnel (1 atmosphere),
- penetrations for hatches, windows, access, etc.,
- a forward aerodynamic fairing for ascent protection,
- secondary structure for supporting internal hardware,
- a large, moveable body flap, and,
- an expendable radiator/OMS module (see Section 9.11).

Each of these elements involves a number of subassemblies; at this level of conceptual study, only limited examination of these subassemblies was conducted.

Options that were considered available technology can be divided into two types: "cold" structure that is thermally isolated from reentry heating, and "hot" (or warm) structure that is designed to take aerodynamic and thermal loads. Table 9.1.1-1 is a list of structural options that were considered as alternatives to the baseline aluminum structural concept. Some of the option's properties are shown as Figures 9.1.1-1 and 9.1.1-2.

The selected material/structural concept is shown in Figure 9.1.1-3. Primarily a welded aluminum skin/stringer design, this concept is a proven, low risk structure. Aluminum honeycomb panels are also used for doors/access panels. Carbon-carbon is used selectively for high temperature regions such as the nose cap and the body flap. The expendable radiator incorporates superplasticly formed (SPF) panels as a way to make low-cost structure with integral cooling passages. An equipment list for the structure is shown as Table 9.1.1-2.

9.1.2 Doors/Hatches/Windows/Access

The design of structural penetrations for hatches, windows, etc. can directly affect crew safety and can reduce operations costs. These penetrations will, unfortunately, result in higher weights and increased production complexity and costs. The PLS design should be a compromise between these issues.

Doors/Hatches - The PLS design must include a door/hatch (assumed interchangeable in this case) for personnel entry into the pressurized compartment. To enhance safety, two separate access hatches are used. This also solves the divergent configuration requirements of ground access and on-orbit docking access.

One door/hatch (see Figure 9.1.2-1) is used primarily for ground ingress while the PLS is in the "vertical" position on the launch vehicle. This 36 inch diameter hatch is similar in design to the one found on the Shuttle Orbiter and can be explosively blown off to facilitate a ground egress emergency. The size requirement for the opening is driven by a scenario where personnel would pass through the hatch in space with their partial pressure suits inflated. Such a scenario would represent a unique situation

Table 9.1.1-1 Features of Candidate Structural Materials

	Material	Key Features	Processes	Issues And Current Status: Database [1]	Issues And Current Status: Development [1]
Resin-Matrix Composites	Graphite/Epoxy (Gr/Ep)	• Well Characterized • Low Temperature (<350°F) System • Low Density • Available In Many Forms (Fiber, Fabric, Chopped Fiber) • Moisture Sensitive • Low Damage Tolerance	• Prepreg Tape/Tow • Filament Winding • Compression Molding • Injection Molding • Pultrusion • Resin Transfer Molding • Transfer Molding	4-5 [2]	3 [2]
Resin-Matrix Composites	Graphite/Bismaleimide (Gr/BMI)	Similar to Gr/Ep, Except It Is Less Developed and It Has: • A Higher Temperature Capability (<500°F) • Lower Moisture Absorption	• Same as Gr/Ep, Although R&D Is Still Underway For Methods Other Than Prepreg Tape Layup	2 [2]	2 [2]
Resin-Matrix Composites	Graphite/Polyimide (Gr/PI)	Similar to Gr/BMI, Except: • It Has a Higher Temperature Capability (<650°F) • Processing is Harder (Larger Amount of Volatiles)	• Same as Gr/BMI	2-3 [2]	2 [2]
Resin-Matrix Composites	Graphite/Polybenzimidazole (Gr/PBI)	• New Material • High Temperature (<750°F) System • Low Density • Difficult to Process (High Curing Temperature) • Low Expected Damage Tolerance	• Prepreg Tape • Compression Molding	1	1
Resin-Matrix Composites	Graphite/modified Polybenzoxazole (Gr/mPBO) [4]	• Same as Gr/PBI, Except It Has A Lower Processing Temperature (650°F, As Opposed To 850°F)	• Same As Gr/PI	1	1
Thermo-Plastics	Graphite/Thermoplastics (LARC-TPI, PPS, TORLON, PEEK, Etc.)	• New Materials • "Tougher" Than Gr/Thermosets • Hot Forming Possible • Low Density • Low-Moderate Use Temperature (< 450°F) • Available in Multiple Forms (fiber, Fabric, Etc.)	• Tape Layup • Hot Forming, Stamping • Compression Molding • Injection Molding	2 [2]	1
Carbon/Carbon	Carbon/Carbon (C/C)	• Emerging Material • Very High Temperature (~3600°F) Capability • Low Density • Poor/Fair Mechanical Properties (Although Near-Constant or Improving With Temperature) • Low Damage Tolerance • Will Oxidize at High Temperatures If Unprotected • Available in Multiple Forms (Fiber, Fabric, Chopped Fiber, Etc.)	• Pyrolysis and Graphitization of Gr/Polymer Precursors (tape, woven, mat, etc.	3-4	2-3
Metal-Matrix Composites	Silicon Carbide Whisker or Particulate-Reinforced Aluminum (dSiC/Al, SiC_w/Al, SiC_p/Al)	• High Elastic Modulus, With Strengths Equal Or Higher Than Al • Density Similar to Al • Near-Isotropic • Formable, Castable, Weldable • Machines Like Metal, Although Tool Wear Rates Are Higher • Available For Various Al Alloys (6061, 2124, 201, Etc.) • K_{Ic} Lower Than Al	• PM • Forging • Casting • Extrusion • Rolling • SPF (Experimental)	3 [2]	2 [2]
Metal-Matrix Composites	Boron Fiber/Aluminum (B/Al)	• High Moduli and Strengths • High Temperature Capability (<800°F-900°F) • Higher Transverse Properties Than Gr/Resin Composites • Density Similar to Al, Higher Than Gr/Resin Composites • Formable, Weldable • Usually 6061 Alloy Matrix	• Hot Pressing (Diffusion Bonding) • Limited Secondary Forming (Creep-Forming, Rolling)	3-4 [2]	2-3 [2]
Metal-Matrix Composites	Silicon Carbide Fiber/Aluminum (SCS/Al)	Similar to B/Al, Except It Has: • Lower Transverse Properties • Higher Fabrication Versatility (→Lower Cost)	• Same as B/Al, Plus Hot Molding (Lower Pressure and Higher Temperature Than Hot Pressing)	3 [2]	2
Metal-Matrix Composites	Silicon Carbide Fiber/Titanium (SCS/Ti)	Similar to B/Al, Except It Has • Higher Temperature Capability (<1200°F) • Better Formability (SPF, SPF/DB) • Higher Transverse Properties • Two Ti Alloys = Ti-6-4 • Higher Density • Higher Cost	• Hot Pressing • SPF, SPF/Diffusion Bonding (DB)	2 [2]	1-2
Metal-Matrix Composites	Graphite/Copper (Gr/Cu)	Similar to B/Al, Except It Has: • Lower Strengths • Higher Temperature Capability (< 1800°F) • Much Higher Density • Higher Thermal Conductivity • Lower Producibility (→Higher Cost) • CDA 110 or 113 Matrix • Various Fiber Options: Pan, Pitch-Base	• Liquid-Metal Infiltration (via Wire Precursor) • Ion-Plating (Experimental)	0-1	0
Metal-Matrix Composites	Ceramic (Al_2O_3, TiC or SiC) Whisker or Particulate-Reinforced Inconel (Inconel 718)	• High Temperature Capability (< 1800°F) • Properties Similar to Inconel, But Lower Density • Near Isotropic • Formable, Weldable • K_{Ic} Probably Lower Than unreinforced Metal	• PM • Rolling • Potential For Forging and Casting	0-1	0
Metals	Nickel Base Alloys (Superalloys) (Inconel 718, Rene'41, Etc.)	• Higher Temperature Capability (<1800°F) • High Strength and Modulus • Isotropic • High K_{Ic} • Various Fabrication Methods and Shapes, Weldable • Very High Density	• Forging • Casting • Rolling • PM	5 [2] [3]	3 [2] [3]
Metals	Titanium Alloys (Ti-6242 Ti-15-3)	Similar to Superalloys, Except They Have: • Lower Density • Lower Temperature Capability (<1000°F)	• All Mill Product Forms • Casting • PM • RSR (Experimental)	5 [2] [3]	3 [2] [3]

[1] Database: 0-5; 5=Extensive 0=Non-existent
Development: 0-3; 3 = In production 0 = Exploratory Research Only

[2] Significant in-house background – see Sections 10.2.1 and 10.2.2

[3] Ratings may be lower depending on specific alloy

[4] mPBO is a Boeing - proprietary chemical modification of PBO resin that can be cured at 650°F thus autoclaves installed to process PI resins can be used for mPBO resins. Also, products with low void contents have been consistently fabricated.

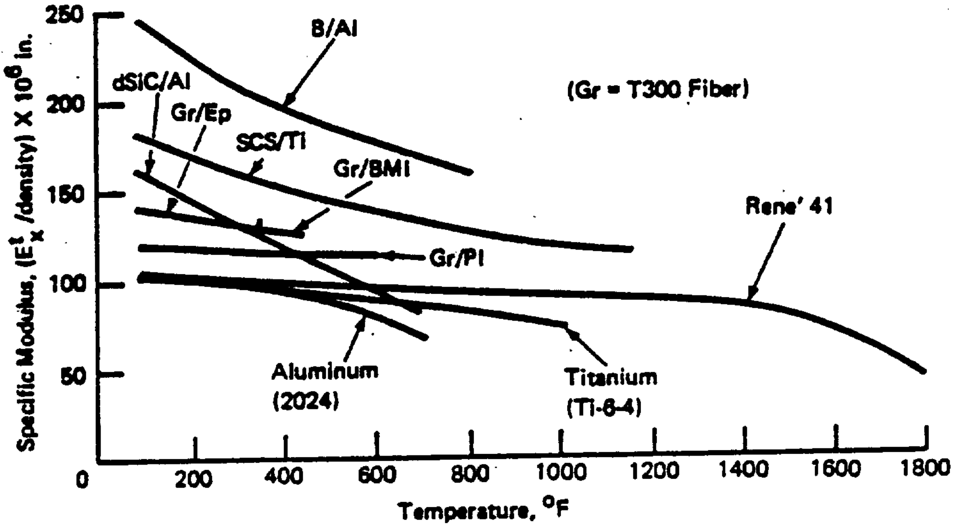


Figure 9.1.1-1 Specific Elastic Modulus vs. Temperature for Quasi-Isotropic Composites and Metals

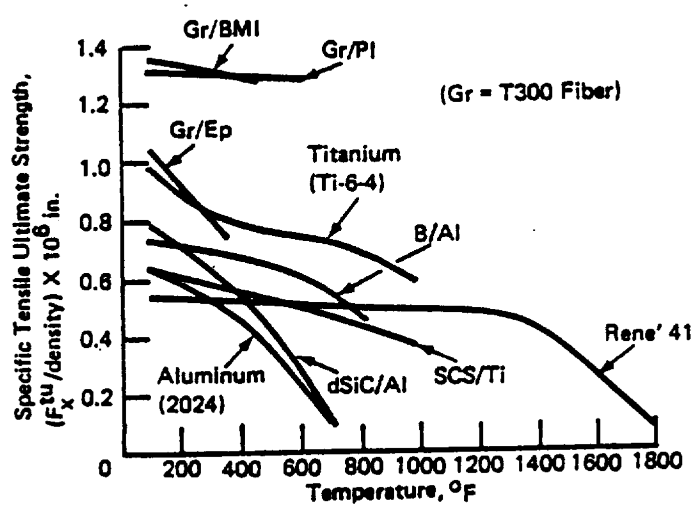


Figure 9.1.1-2 Specific Tensile Strength vs. Temperature for Quasi-Isotropic Composites and Metals

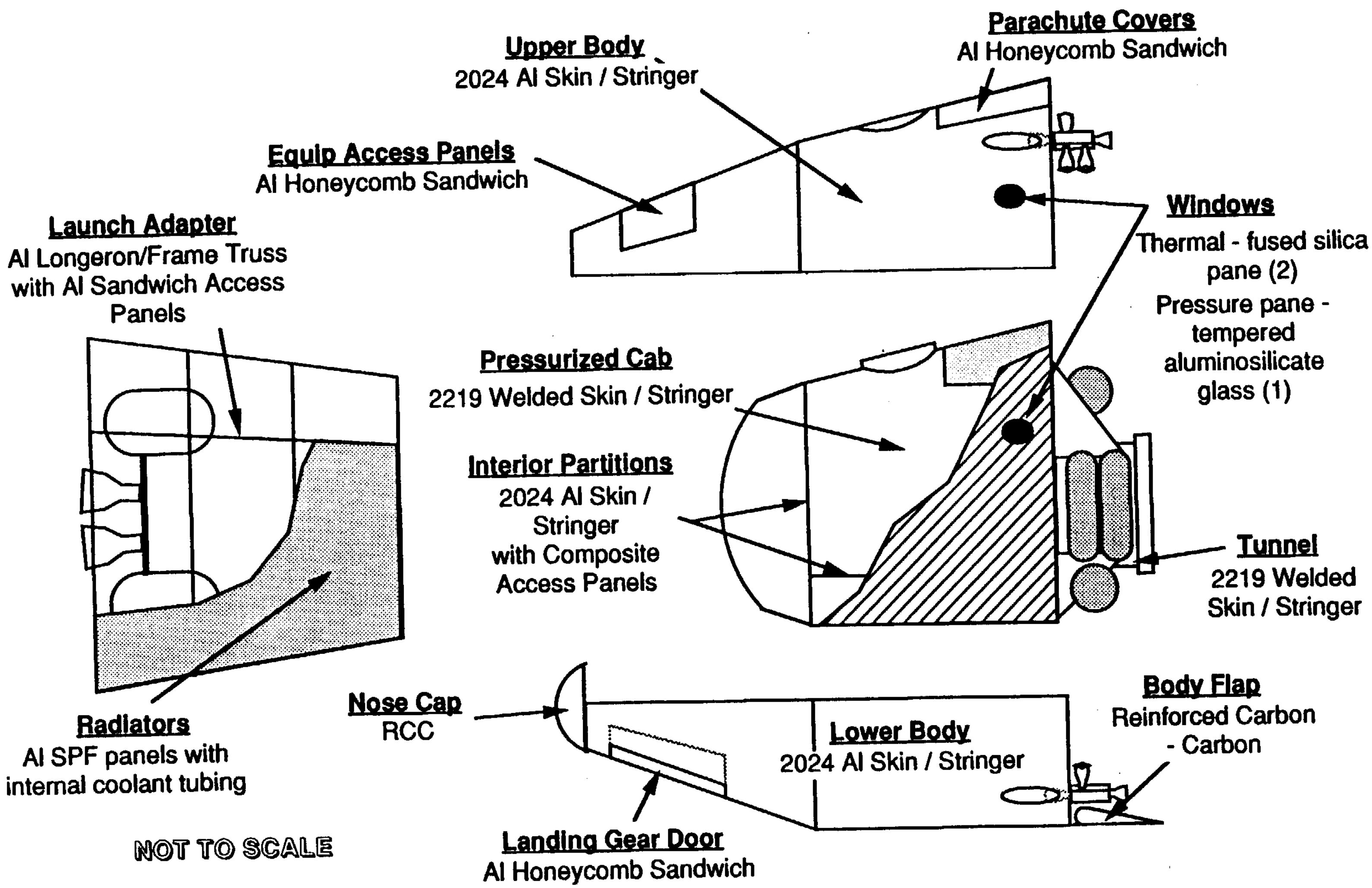


Figure 9.1.1-3 Selected Structural/Material Concept

Table 9.1.1-2 Structural Equipment List (Page 1 of 2)

WBS	ITEM	CREW ROTATION QTY	CREW ROTATION WEIGHT (LB)		DESCRIPTION	MATERIAL
	FWD BODY			1016		
	FRAMES, BULKHEADS		207			ALUMINUM
	COVER PANELS, LONGERONS		402		S=162 SF	AL SK/STR
	LANDING GEAR WELL, COVER, MECHS		201			AL SK/STR
	ACCESS PANELS	2	96		S= 16 SF EACH	
	UMBILICAL PLATES	2	50			
	EQUIPMENT SUPPORT RACKS		60		S= 30 SF	ALUMINUM
	MID/AFT BODY			1345		
	FRAMES, BULKHEADS		408			ALUMINUM
	COVER PANELS		685		S=321 SF	AL SK/STR
	FTGS, CABIN ATTACHMENT	22	33			
	WINDOW, THERMAL	2	19		S=0.8 SF EA	
	PARACHUTE COVERS, ACTUATORS	2	88		S= 12 SF EACH	
	RMS GRAPPLE FITTING	2	44			TITANIUM
	BODY FLAP CLOSEOUT, HINGE SUPT	1	68		S=7.5 SF	
	PRESSURIZED CABIN			2476	ALL WELDED	
	PRESSURE BULKHEADS	1	450			2219 AL
	FRAMES, PARTITIONS	3	295			2219 AL
	COVER PANELS - CABIN, TUNNEL		673		S=400 SF	2219 AL
	EQUIPMENT SUPPORT RACKS		150		S=100 SF	ALUMINUM
	FLOORING, EQUIP SUPT		184		S= 92 SF	COMPOSITE
	FTGS, CABIN ATTACHMENT	22	33			
	WINDOWS	4	128		S= 0.8 SF EA	
	DOCKING ADAPTER MECHANISM		340			
	TOP HATCH	1	90		36-IN DIA	
	DOCKING HATCH, STRUCTURE	1	133		40-IN DIA, SHUTTLE-TYPE	
	BODY FLAP			400		
	STRUCTURE	2	279		S= 31 SF	RCC, INSTL
	ACTUATOR, INSTALLATION	4	121		DUAL REDUN, E/M ACTUATORS	
1.1.3	**STRUCTURE - CREW MODULE**			**5237**		

Table 9.1.1-2 Structural Equipment List (Page 2 of 2)

WBS	ITEM	CREW ROTATION QTY	CREW ROTATION WEIGHT (LB)		DESCRIPTION	MATERIAL
	FRAMES, BULKHEADS	4	384		Fwd, aft interface, intermed. frames	ALUMINUM
	LONGERONS	6	257		L=11.9 FT	ALUMINUM
	SECONDARY STRUCTURE / FTGS		248		Frame Stabilization, Access Panels	ALUMINUM
	THRUST STRUCTURE	6	143			ALUMINUM
	THRUST RING / FTGS	1	25			ALUMINUM
	ENG INTERFACE FTGS	3	9			
	TANK SUPPORT STRUTS	24	138			ALUMINUM
	RADIATOR PANEL LINKAGE & HINGES	2	40			
	LAUNCH / CREW MOD UMBIL PLATES	2	60			
	PRESS BOTTLE SUPT FLANGES	8	8			ALUMINUM
1.6.3	**STRUCTURE - OMS MODULE**			**1312**		
	ENGINE THRUST STRUCTURE		173			
	STABIIZING STRUTS, ETC		87			
1.6.3	**STRUCTURE - LAUNCH ESC SYS**			**260**		

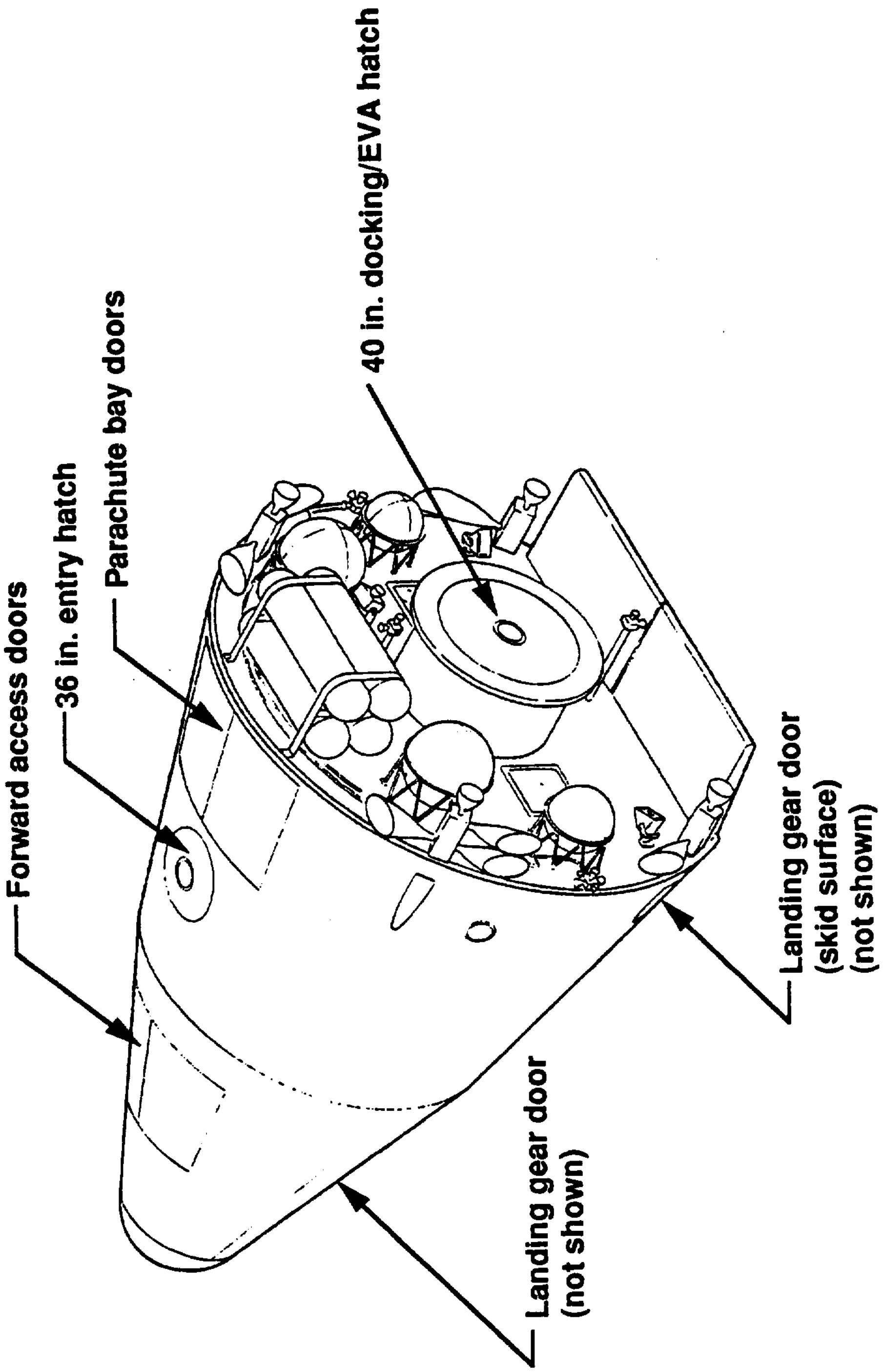


Figure 9.1.2-1 PLS Doors/Hatches/Access Panels

(potentially an emergency) where the normal docking hatch is not available or functioning.

The other door/hatch is used primarily in conjunction with the docking mechanism mounted around the hatch (refer to Section 9.1.3). This hatch, located on the back bulkhead of the biconic, features a 40 inch diameter opening to facilitate moving personnel and equipment between the PLS and other orbiting habitats. On the launch pad, access to other PLS systems external to the biconic is through a series of removable panels, all on the launch tower side of the PLS "stack" (see Figure 9.1.2-2).

Windows - Windows are included primarily to provide visual cues in operations were crew members are assuming control from automatic systems. Observations can verify orientation/navigation, supervise telerobotic operations, assist in scientific studies, and enhance the psychological state of the crew. Windows are typically designed in layers to accommodate pressure, thermal, and micrometeorite impact loads.

The PLS incorporates 5 windows in the biconic design (see Figure 9.1.2-3). The two major viewing ports are located on the aft bulkhead directly in line with the eyes of the flight crew. These relatively large windows, with scribe marks and mirrors, enable the crew to see docking/servicing alignment, aerodynamic surface (body flap) position and function, landing gear deployment, and terminal deceleration/impact obstacle avoidance. The hatch on the side (top when "horizontal") contains a small window for pre-egress visual inspection, scientific observations, attitude verification, and visual inspection of deployed parafoil/parachutes. Two small windows on either side of the crew would be used for attitude verification and scientific observations. Simulations and mockups will be required to verify the location, size, and number of windows.

Access - External access provisions are one key element in designing for a maintainable system. From a purely operational standpoint, the ideal PLS would have opening access ports over a large percentage of the surface area. In reality, each opening represents a design complexity; load bearing surface panels create gaps in the TPS, which require seals, fasteners, and mechanisms, and require strengthening (adding weight) of the surrounding structure, all of which can lead to <u>increases</u> in maintenance time. Internal access is not the total answer, either, as the physical congestion of workers inside a small vehicle can complicate ground operations (as was seen in the Apollo program). The compromise position on access will be decided at a later stage of PLS development.

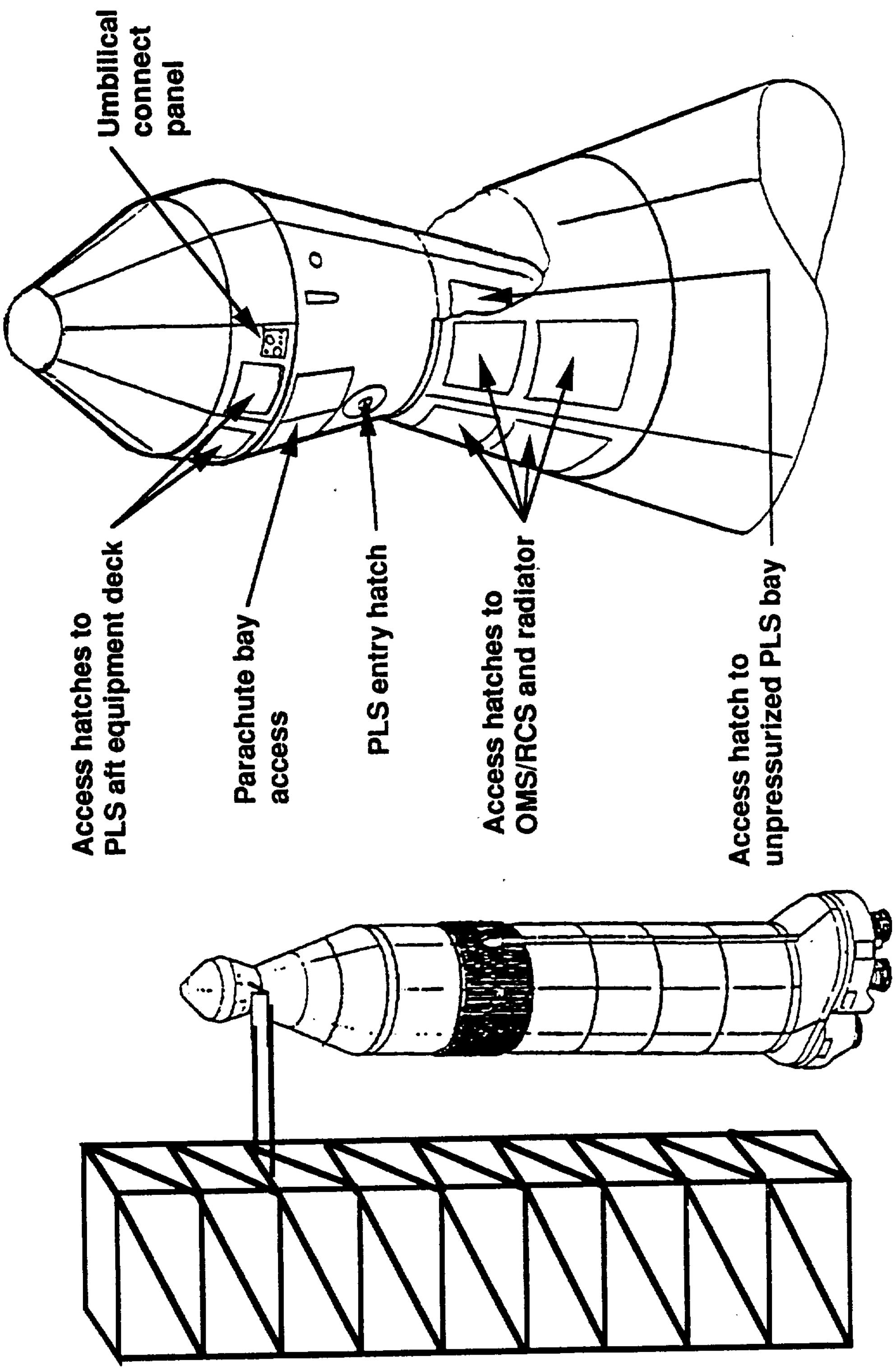
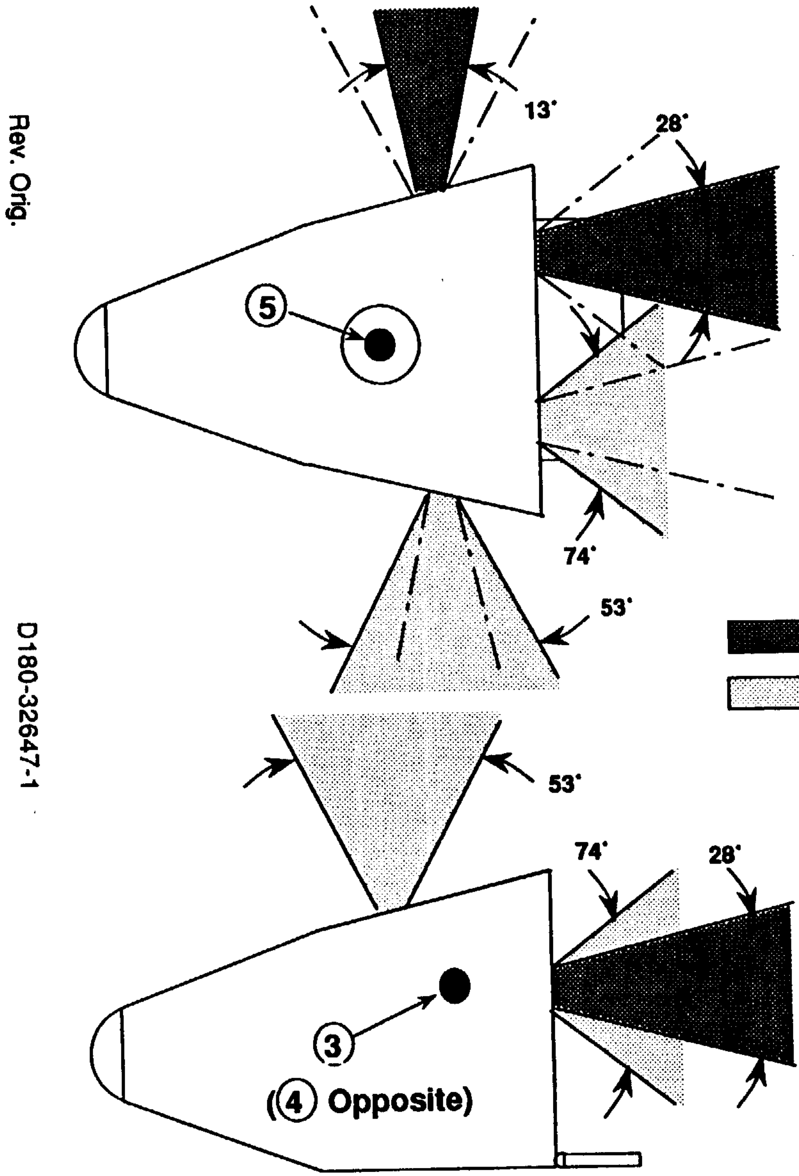


Figure 9.1.2-2 Launch Pad Access Panels

Window	Size	Nominal Eye Distance*	Off design Eye Distance*
1	18 inch sq.	34 inches	12 inches
2	18 inch sq.	34 inches	12 inches
3	12 inch dia	52 inches	12 inches
4	12 inch dia	52 inches	12 inches
5	12 inch dia	N/A	12 inches

*Distance from viewing point to inside window surface



Design Field of View

Off Design Field of View

BOEING

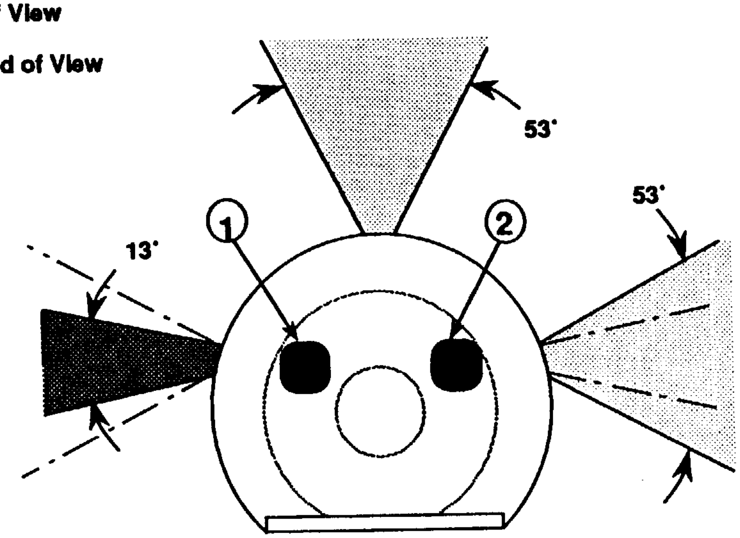


Figure 9.1.2-3 Window Location and Fields of View

9.1.3 Docking Hardware

The PLS mission model requires the vehicle to dock, primarily with the SSF. Objectives for other missions, such as the rescue and servicing missions, imply that the PLS must have the capability to dock with a variety of spacecraft (such as the Shuttle Orbiter, Mir, etc.) which will probably be uncooperative. Issues relating to docking hardware include:

- Interface (physical fit, connections/umbilicals)
- Pressure (seals, equalization of differences, vent/fill between hatches)
- Loads (bending, pressure, shock)
- Thermal protection (orbital distortion, reentry flow)
- Safety (positive release, seals)
- Reliability (fault tolerance)
- Active/passive roles

In addition, the hardware must include any alignment/sighting grids required for piloted docking. Two grapple fixtures (see Figure 9.1.3-1), such as those used on Shuttle payloads, are required to allow the SSF to position the PLS. Proximity thrusters are discussed in Section 9.3.3 and range/range rate sensors and instrumentation are discussed in Section 9.6. Current SSF operating rules would use the SSF's Remote Manipulator System (RMS) to dock or berth the PLS.

The size of the docking hatch would vary with each proposed spacecraft with which the PLS mates. The current SSF berthing ring (see Figure 9.1.3-2), while obviously near ideal for SSF docking, would have serious design implications for a PLS. The physical size of this ring integrates poorly with PLS designs of the size that this study is exploring. At the same time, the attachment mechanism (i.e. powered bolts) is not well suited for the repeated cycling that is required for berthing.

The Shuttle Orbiter is proposing to use a different docking adapter for it's visits to the SSF (see Figure 9.1.3-3). The active hardware mounted in the front of the payload bay would again be inappropriate in size and weight for use on a smaller PLS. The

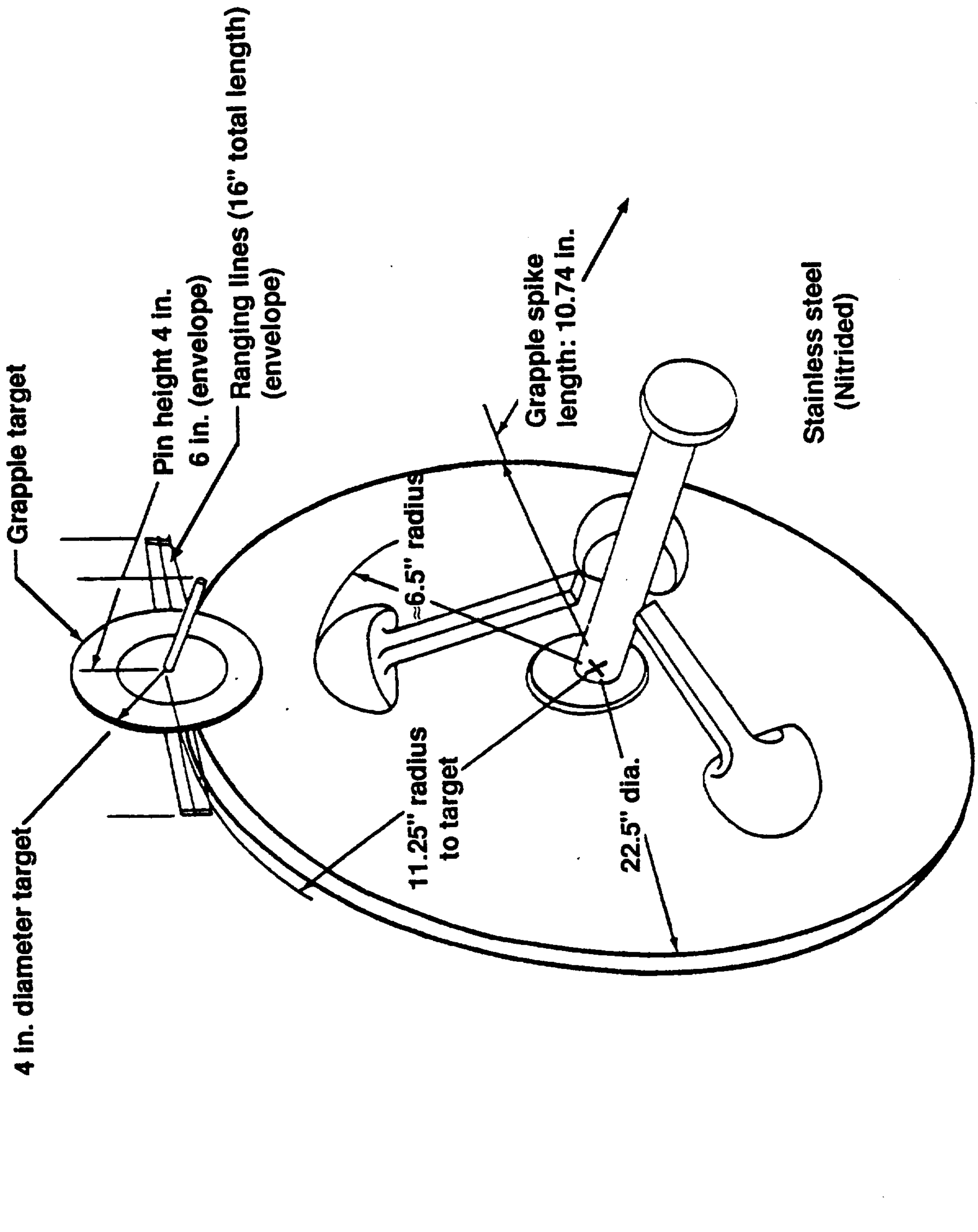


Figure 9.1.3-1. RMS Standard Grapple and Target Fixture

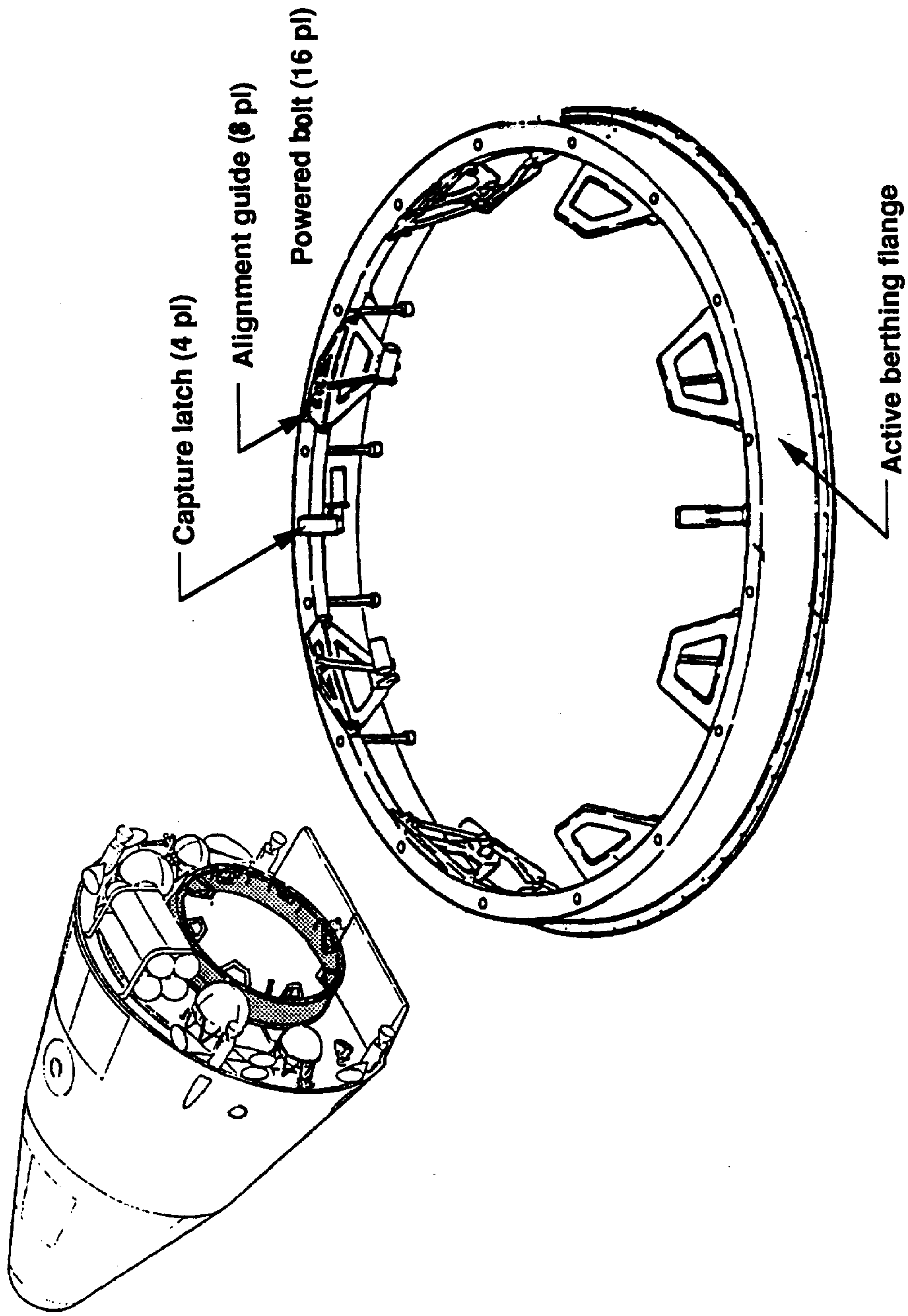


Figure 9.1.3-2. SSF Active Berthing Ring

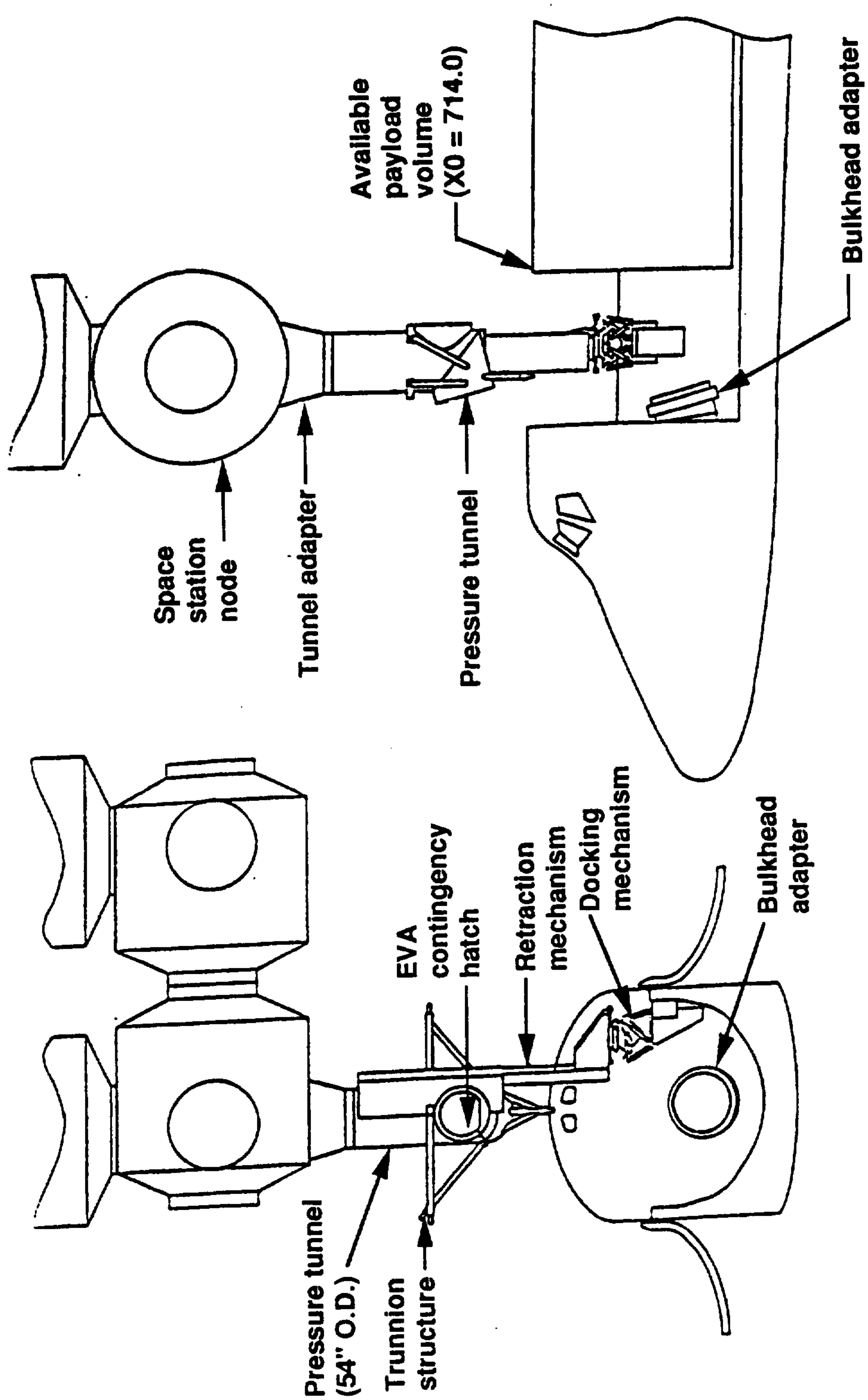


Figure 9.1.3-3. Shuttle Orbiter Docking Adapter

hatch size (40 in. diameter) does seem acceptable and much of the hardware design could be used.

Whether or not a new docking port/adapter is required on SSF for PLS remains to be determined after the SSF design is frozen. Regardless, the PLS will require a standard interface plane to which a variety of docking adapters could be mechanically attached for the various missions. The actual docking mechanisms are to be determined. Depending on the design, the docking hardware will probably adversely affect the vehicle's reentry aerodynamics and/or balance and will be exposed to high temperatures with little thermal protection.

9.2 Thermal Protection System (TPS)

The PLS capsule will experience a wide range of temperatures and heating rates during each flight. Aerothermal heating, which is most severe during the reentry phase, is a function of vehicle geometry and the descent trajectory.

A variety of materials for TPS have been successfully used since the beginning of manned spaceflight. However, none of the methods used to date meet the operability or cost goals of the PLS. There are materials that have resulted from years of steady technology improvements which potentially would solve the previous TPS shortcomings (see Section 16).

Figure 9.2-1 illustrates options for TPS materials. Some key features of these materials are listed in Table 9.2-1. There are many opinions as to what system is best, primarily due to the long years of work that have been done by a variety of government, industry, and academia research groups. There are some generalities that transcend opinion which are important to note:

1) Ablators have been used successfully by the vast majority of reentry vehicles (manned and unmanned, terrestrial and planetary). Ablators tend to be heavy, require some additional refurbishment, and many contain organics which can outgas in space and "pollute" the local environment.

2) Ceramic reusable tiles have been used successfully on several dozen flights (Shuttle, Buran) and offer a lightweight solution. Even assuming that the difficulties of bonding/attachment are eventually solved, ceramics

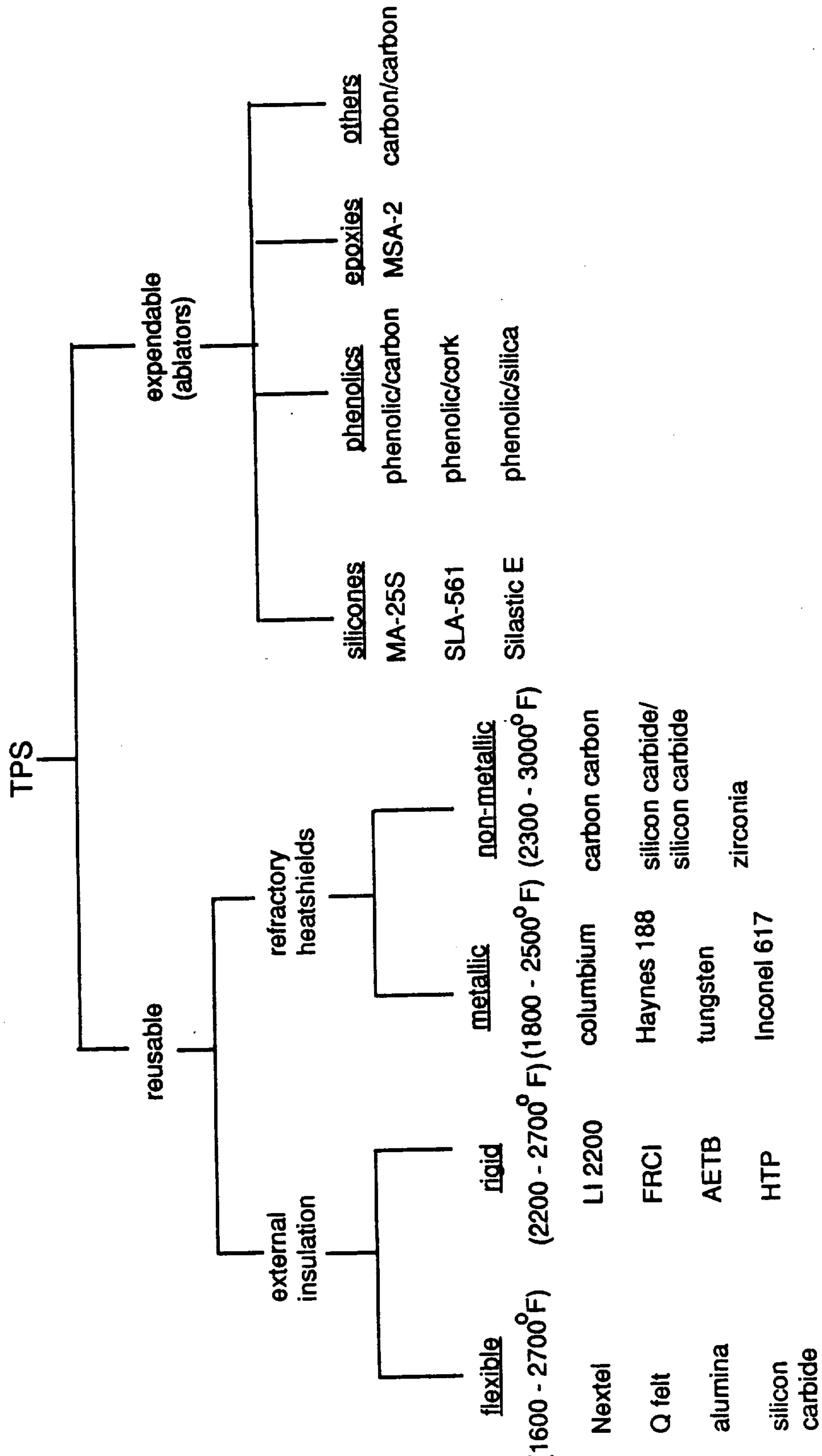


Figure 9.2-1 TPS Materials Options Tree

Table 9.2-1 TPS Material Properties

Material Category	Examples	Max Temp (deg F)	Advantages	Disadvantages and Concerns
metallic refractories	columbium tungsten	2500	durability reuse	cost unforgiving weight
superalloys	Inconel 617 Haynes 188 Rene 41	2000 1850 1600	durability reuse	temp capability
non-metal refractories	carbon/carbon silicon carbide/ silicon carbide	3000* 2700	reuse	cost weight
ceramic tiles	FRCI AETB	2400 2700	weight reuse	cost durability
hi density ablators	phenolic silica phenolic carbon		heating capability	no reuse weight insulation required
med /low density ablators	phen cork filled silicone filled epoxy		insulating capability limited heat capability	no reuse
hi-temp fabrics	Nextel silicon carbide	2000 3000	reuse	durability

* limited by available coatings

(even coated) would not be considered robust in ground handling by aircraft standards.

3) Metallic or composite skins offer excellent durability and could eliminate virtually all TPS servicing/inspection. The least proven, these skins have some technology risk, although large efforts, such as those on the National Aerospace Plane (NASP), are making significant strides in these materials.

4) Coatings are required in most TPS concepts to protect from moisture, oxidation, atomic oxygen, etc. Coating technologies will determine the operational success of any TPS candidate.

Describing the aerothermal environment can be a complex task, driven by a variety of factors. Some background theory is provided here to understand the basic factors.

One parameter that is frequently used to relate drag to the weight of a reentry vehicle is the ballistic coefficient, ß, which is defined as:

$$\beta = W/SC_D$$

Here S is defined as the frontal area or projected area normal to the flow. Typical values of ß vary typically from 100 to 1000 psf:

Apollo CM= 75 psf

STS Orbiter= 55 psf (max C_L) to 350 psf (max L/D)

Gemini= 75 psf

Mercury= 55 psf

P/A Module= 90 psf

PLS Biconic= 125 psf (max C_L) to 305 psf (max L/D)

A vehicle with a high ß and low L/D falls rapidly, creating a high amount of aerothermal frictional heating. Figure 9.2-2 relates these trends to q (or QDOT), the heating rate. The absolute value of $\dot{q}$ is not the message here, but rather the relationship of L/D and ß and the fact that a moderate L/D, say 0.5, is above the "knee" in the curves and

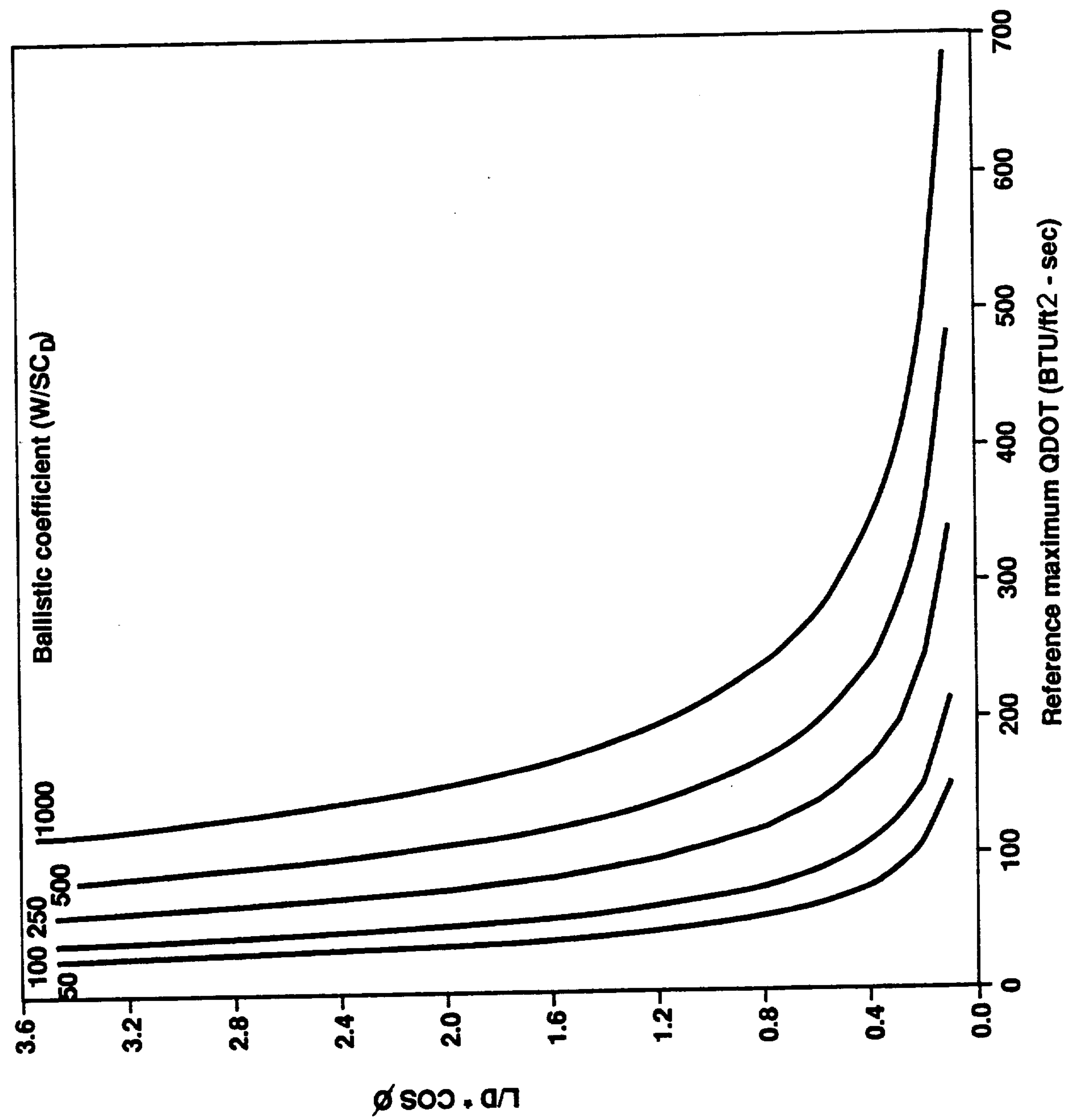


Figure 9.2-2 L/D versus QDOT for Various Values of B

further L/D improvements only slightly reduce $\dot{q}$. Note that the L/D is usually multiplied by the cosine of the bank angle (Ø) to account for the fact that a typical trajectory will modulate bank angle for crossrange and/or heating control. The total heating "load" is defined as:

$$Q = \int \dot{q}\, dt$$

Reducing drag to increase L/D (and thus reduce $\dot{q}$) is more difficult than producing more lift. The amount of hypersonic lift is directly proportional to the size of the "wing" or the area normal to the flow. Using the lift can reduce the peak heating rate (see Figure 9.2-3) but will increase the total Q. For reference, Figure 9.2-4 depicts several reentry heating vs time plots of different vehicles.

Some TPS requirements are driven by maximum temperature, while others are driven by heating rate or integrated heat load. For example, surface temperature may limit the selection of materials for an ablator, but the heating load would determine the ablator thickness. An actively cooled skin, on the other hand, would be limited by $\dot{q}$, not maximum temperature. The relationship between temperature and heating rate, even for a ballistic trajectory, depends on several variables. Figure 9.2-5 shows a typical relationship for a reference one foot radius sphere with a surface emmisivity of 0.8. Of course, a "sharper" leading edge (a smaller radius of curvature) would be hotter, and a larger curvature would result in a lower temperature (see Reference 14).

Within the scope of this contract, several "low L/D, no wings" concepts were explored. A series of trajectories was run on each of 3 candidate PLS shapes. In the absence of other requirements, the following methods and assumptions were used:

- boundary layer using rho-mu (laminer) and Spalding-Chi (turbulent),
- flow field using Savage & Jaeck (Reference 15), nose bluntness effects using Blick and Francis (Reference 16),
- standard 1962 atmosphere,
- factors applied to heat transfer coefficients include dispersions (1.2), guidance (1.2), and surface catalysis (0.7 for reusable TPS schemes),
- gas properties assumed using chemical equilibrium using Peng & Pindroh (Reference 17) transport properties, and,

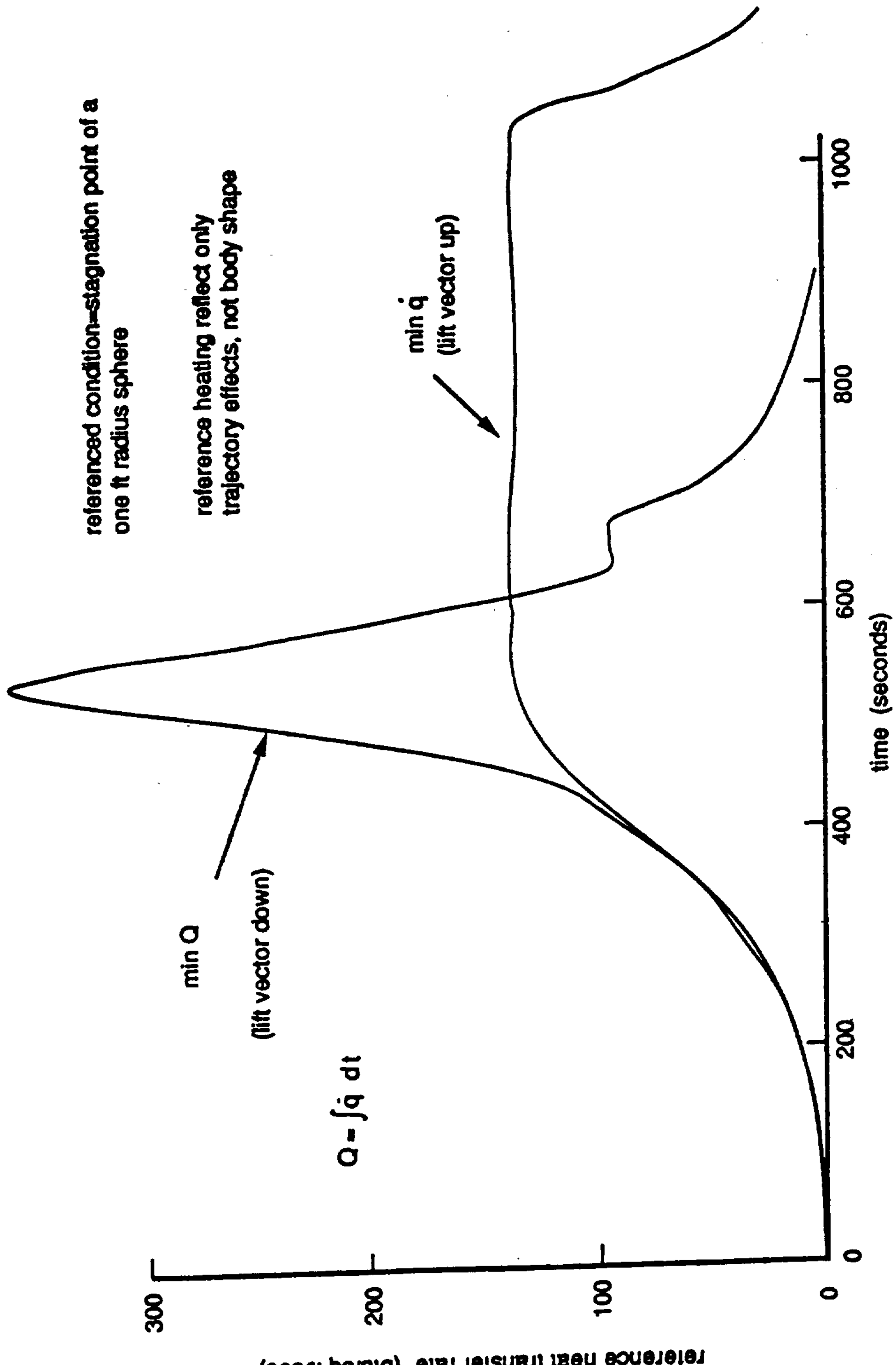


Figure 9.2-3 Reference Heating Plates

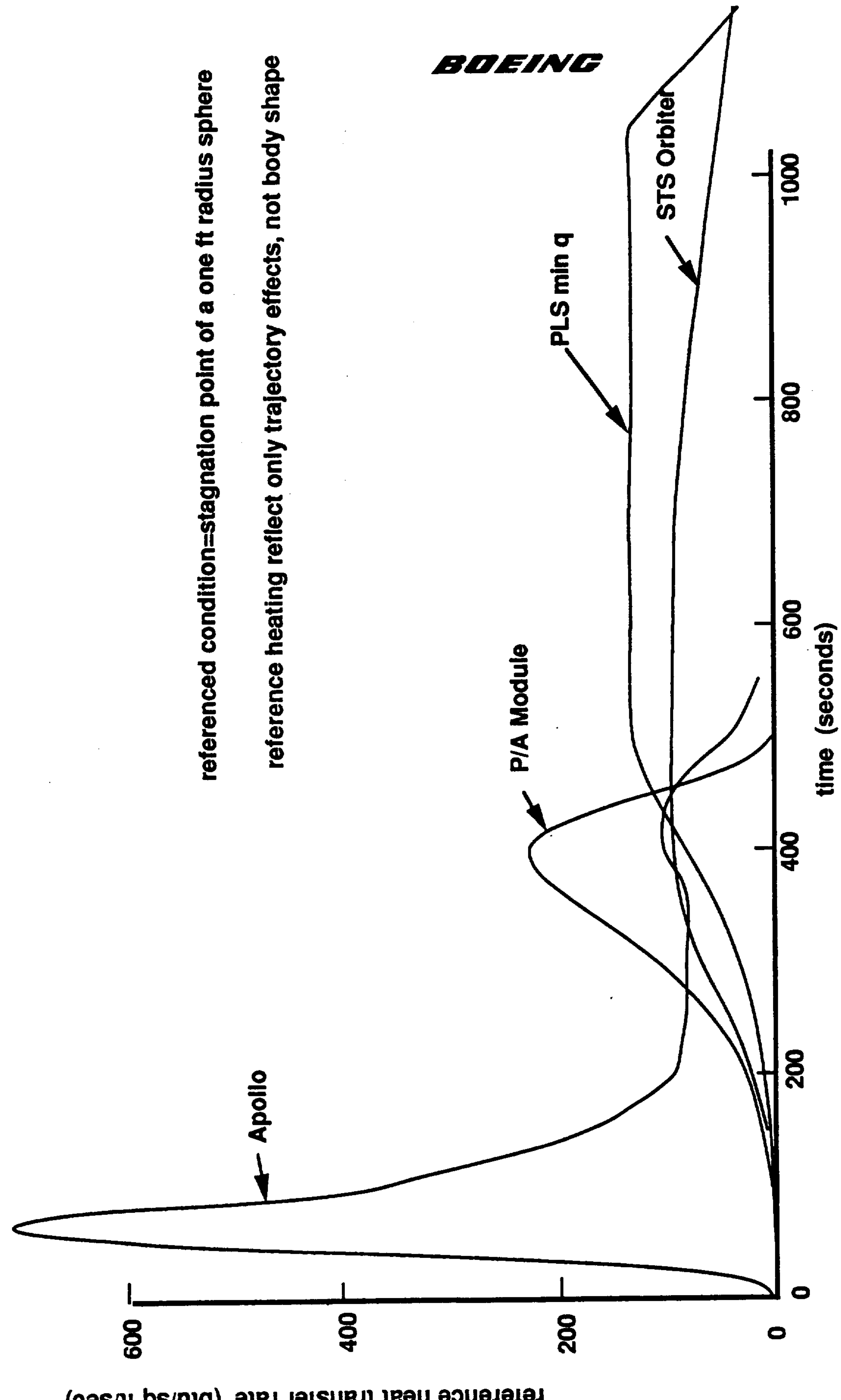


Figure 9.2-4 Reference Heating Comparisons

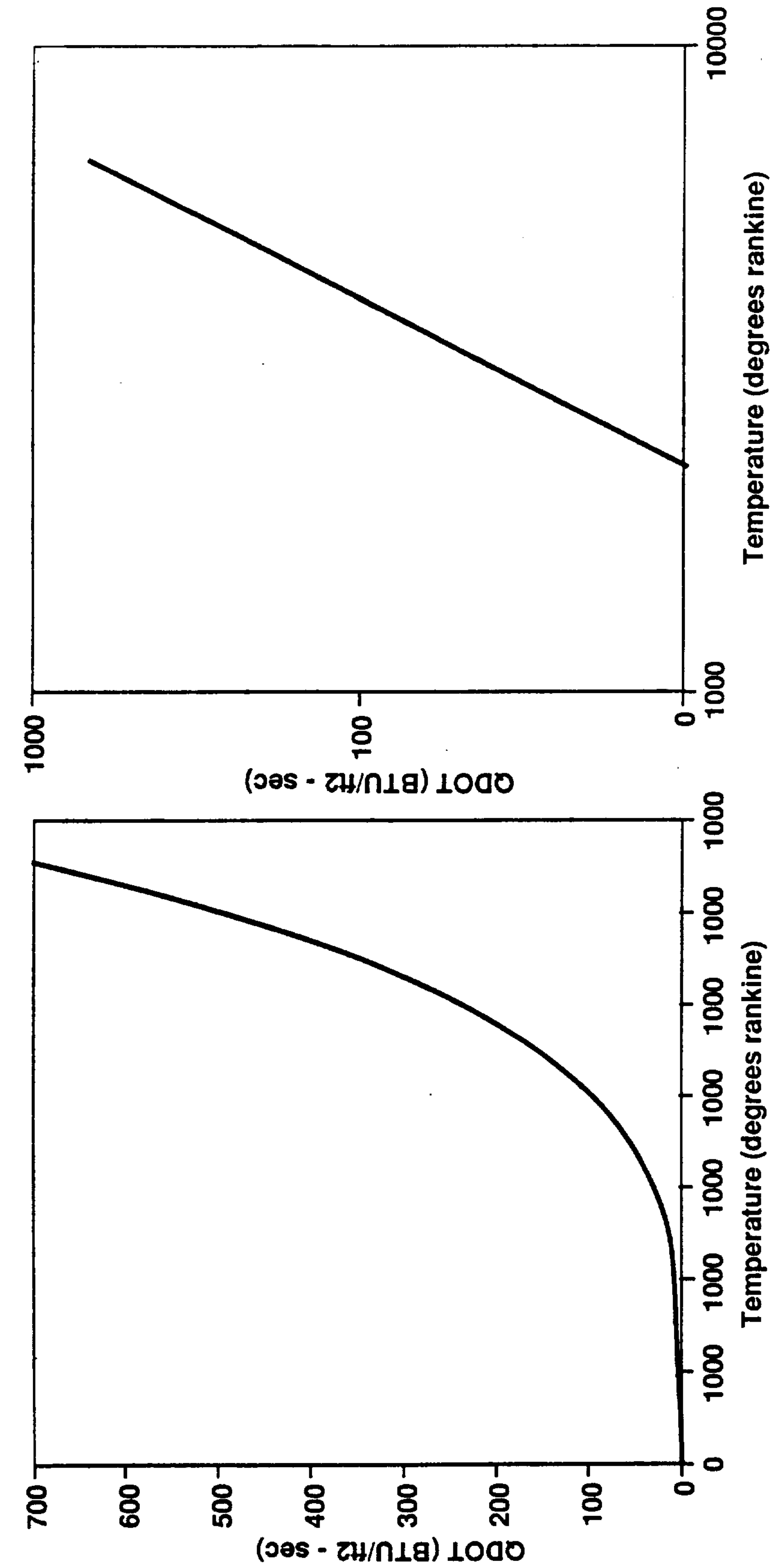


Figure 9.2-5 Heating Rate versus Temperature

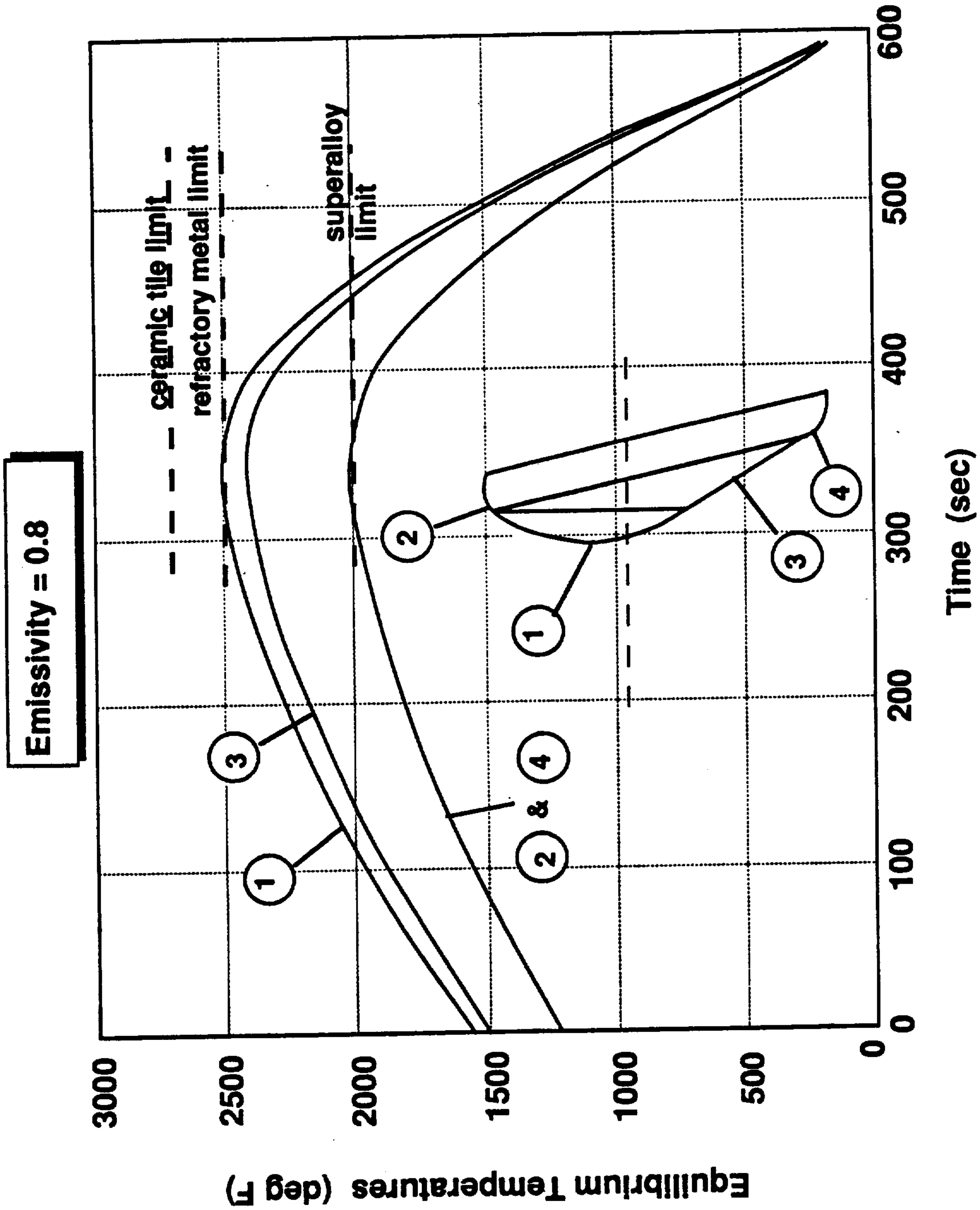


Figure 9.2-6 EquilibriumTemperatures (Shaped Brake)

- backwall cooling assuming sink temperature of 80° F and a convective cooling coefficient of 0.002 lb/ft^2/s

The first plot (Figure 9.2-6) is for a low L/D "shaped brake" concept. The large area (high C_D) results in temperatures well within the limits of existing material concepts. Figure 9.2-7 is a reentry trajectory for the shaped brake showing altitude (vertical axis), crossrange and downrange (horizontal axes), attitude (bank of the "ribbon"), and peak stagnation temperature in degrees Fahrenheit. The next two plots are for the preferred biconic configuration. The first plot (Figure 9.2-8) depicts a minimum $\dot{q}$ trajectory which shows that all of the vehicle except the nose cap area falls below the limit of Shuttle Orbiter tile technology. The other plot (Figure 9.2-9) is for a minimum total load, Q, which results in very high temperatures over the entire vehicle for a period of time. These two plots would probably bracket the actual trajectory - remember that these trajectories do not necessarily represent the optimum for a desired crossrange/downrange and/or minimum g loading. Figure 9.2-10 is an example trajectory temperature plot (similar to 9.2-7) for the biconic configuration. The third vehicle examined represents the "high end" of the no-wings PLS shapes. Called a "wedge", the shape is a modification of the biconic that features a larger, flat lower surface planform. Note on the plot (Figure 9.2-11) that, except for the nose region, the surface temperatures are reduced to the point were robust hot metal concepts can be considered. Figure 9.2-12 is a trajectory temperature plot for the wedge configuration. This concept is discussed in more detail in Section 16.

As mentioned in the previous section, the structure and the TPS are very interrelated. Figure 9.2-13 portrays a variety of concepts for TPS/structure (not to scale). NASA has a great deal of recent experience with ceramic tile TPS. For the baseline PLS biconic design, this ceramic tile is used extensively (see Figure 9.2-14). This solution can be weighed and costed with a high degree of confidence. Internal thermal protection (Figure 9.2-15) consists of insulation for further thermal control. An equipment list for the various protection systems is shown as Table 9.2-2.

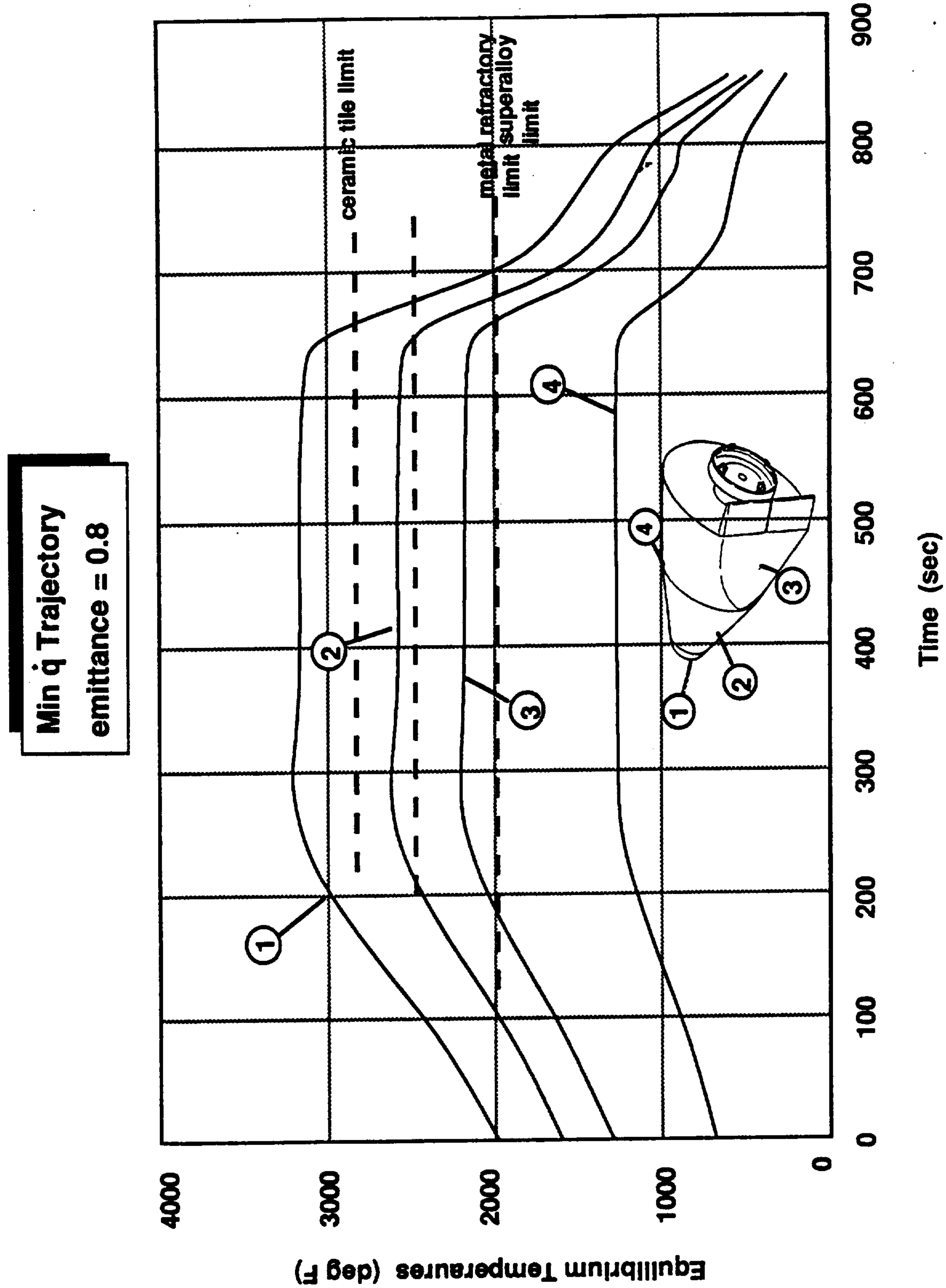


Figure 9.2-8 Equilibrium Temperatures (Biconic) For a Minimum QDOT Trajectory

BOEING

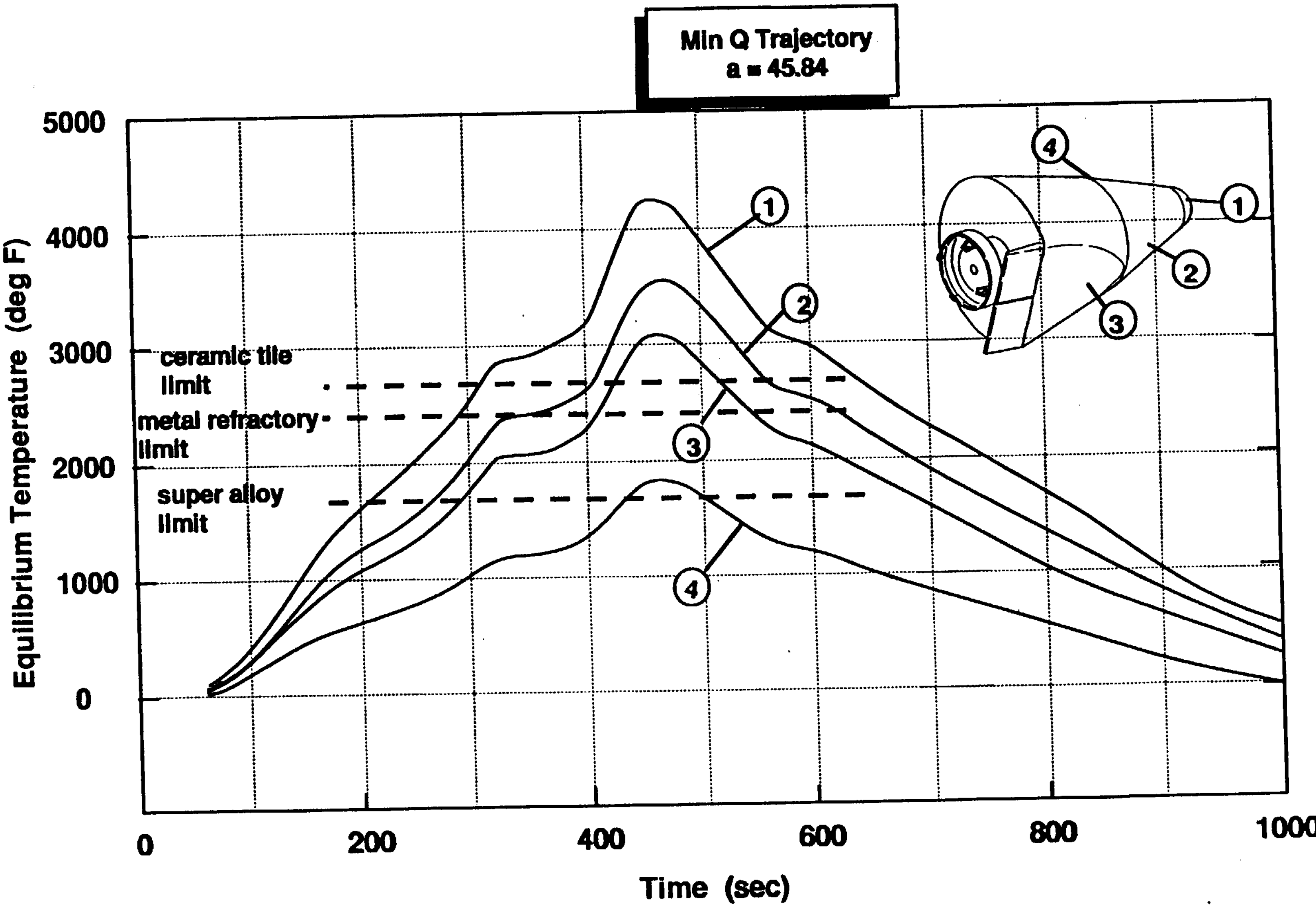


Figure 9.2-9 Equilibrium Temperatures (Biconic) For a Minimum Q Trajectory

[redacted]

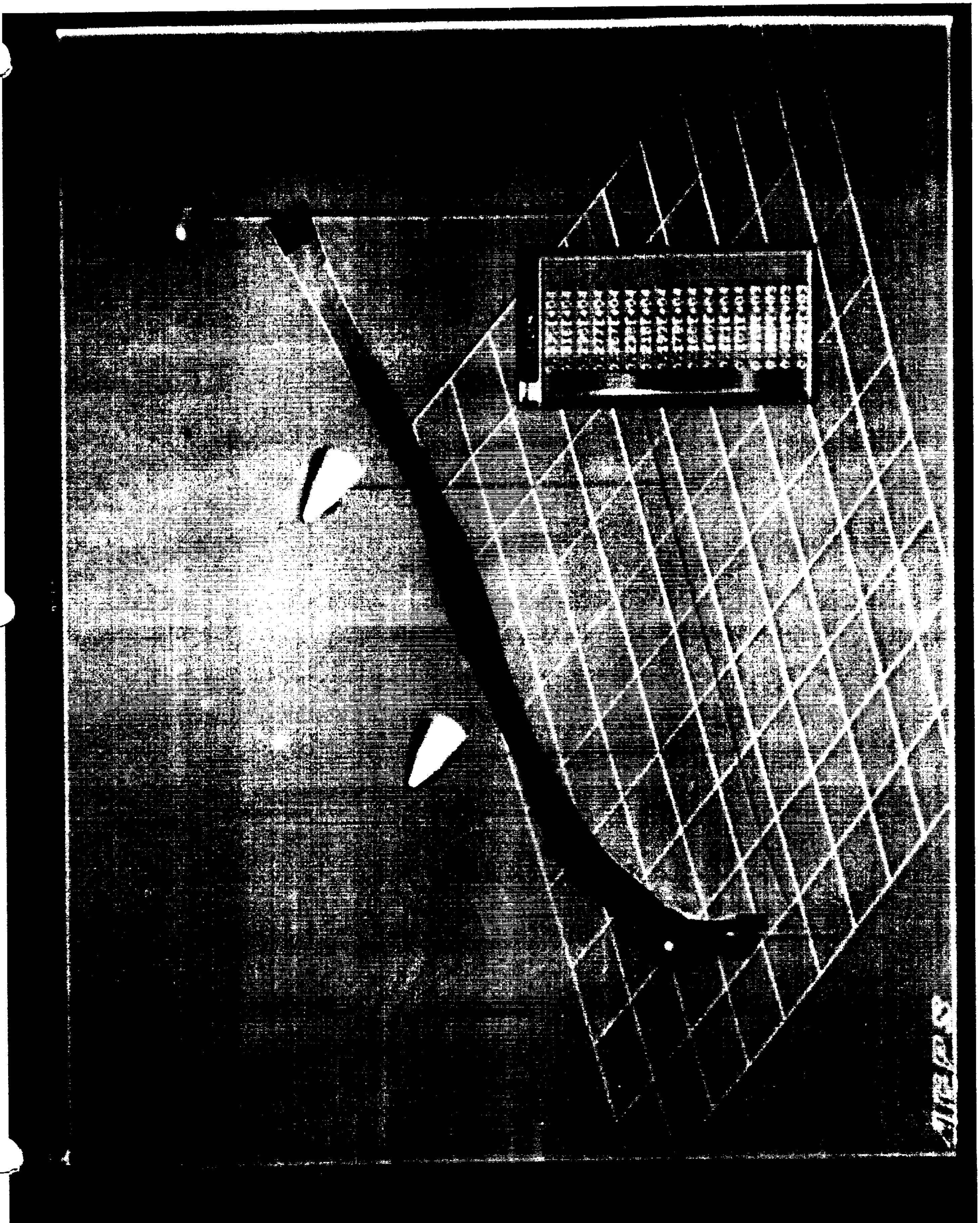


Figure 9.2-10 Trajectory Temperatures for Biconic Configuration

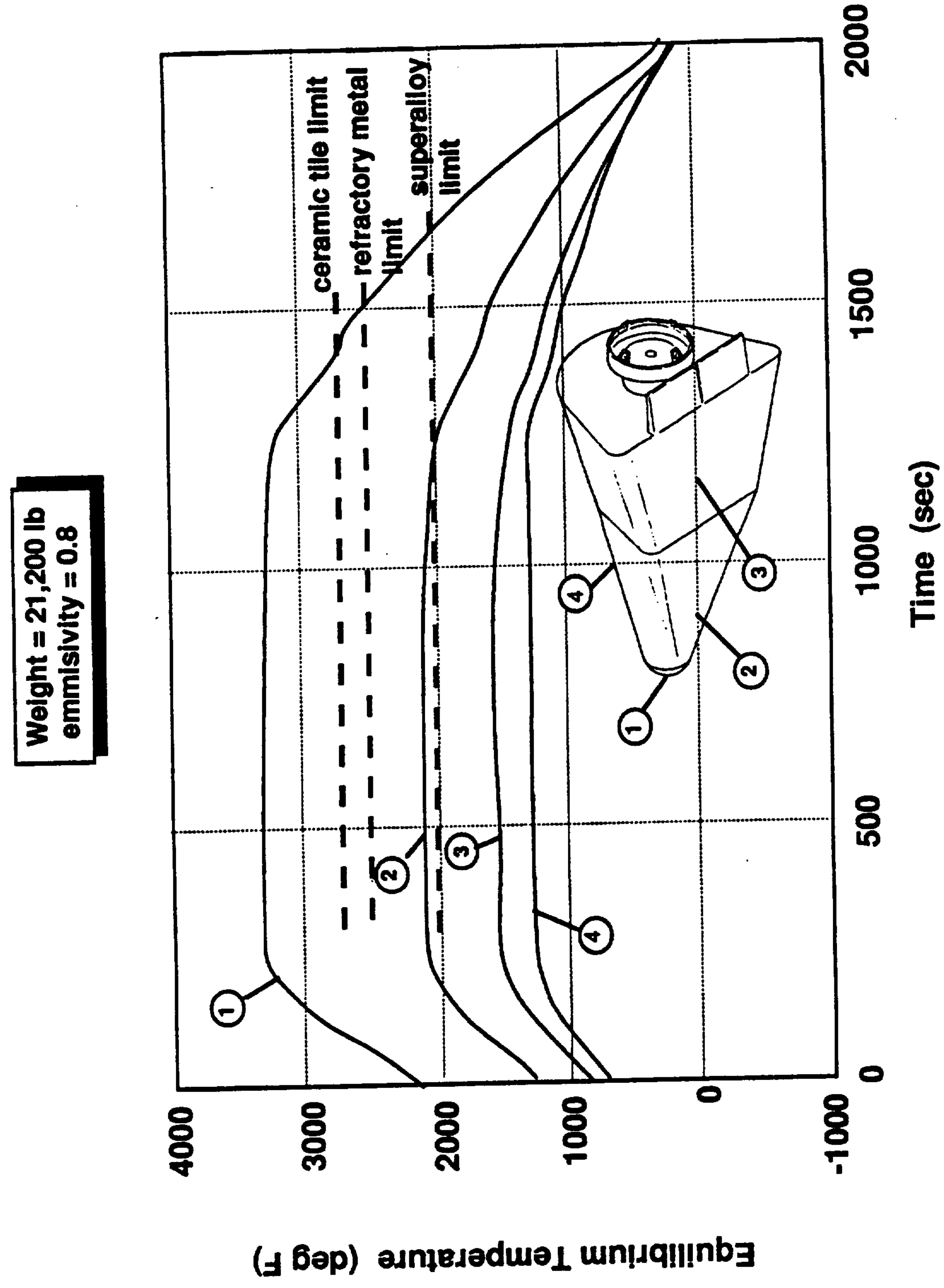


Figure 9.2-11 Equilibrium Temperatures (Wedge)

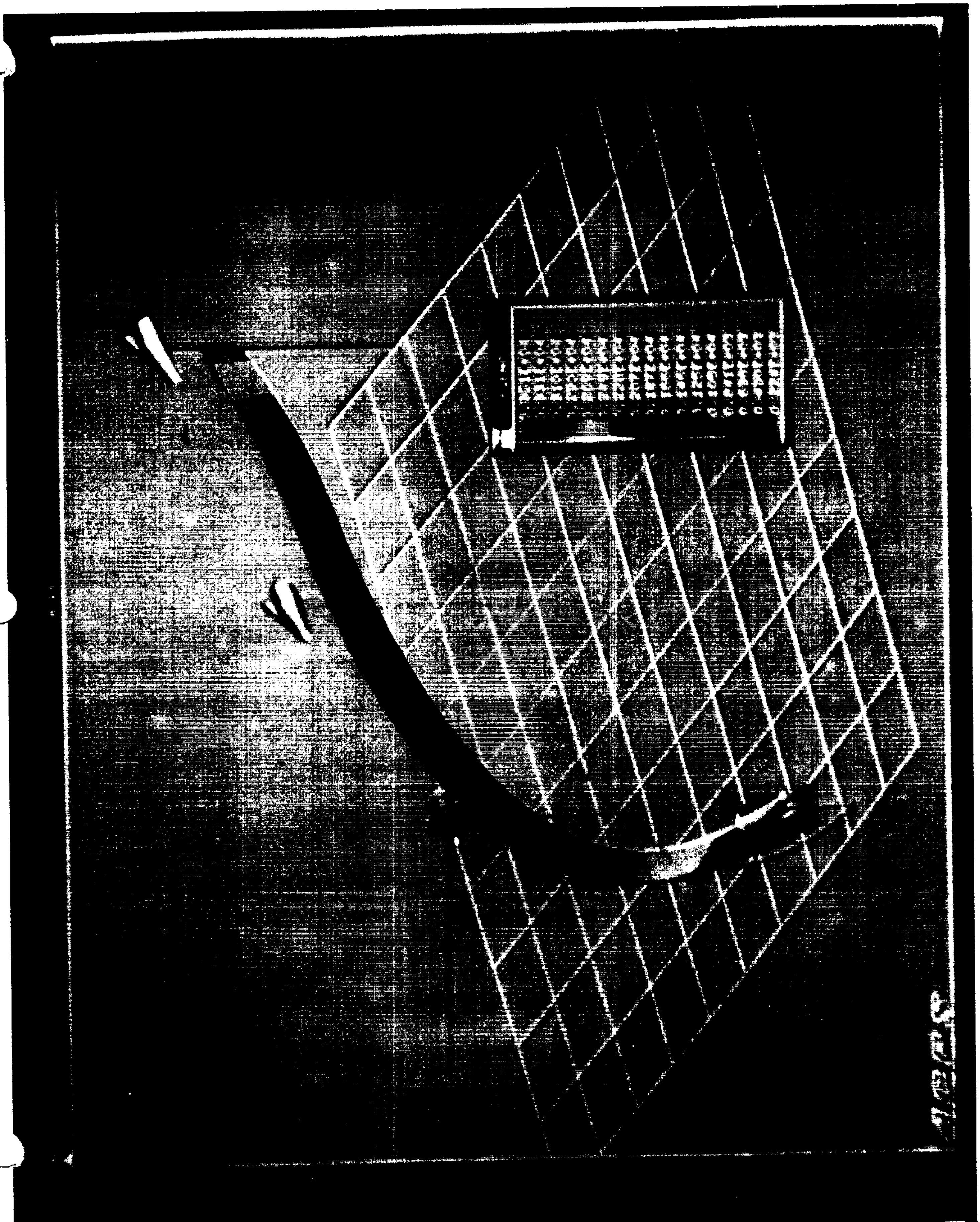
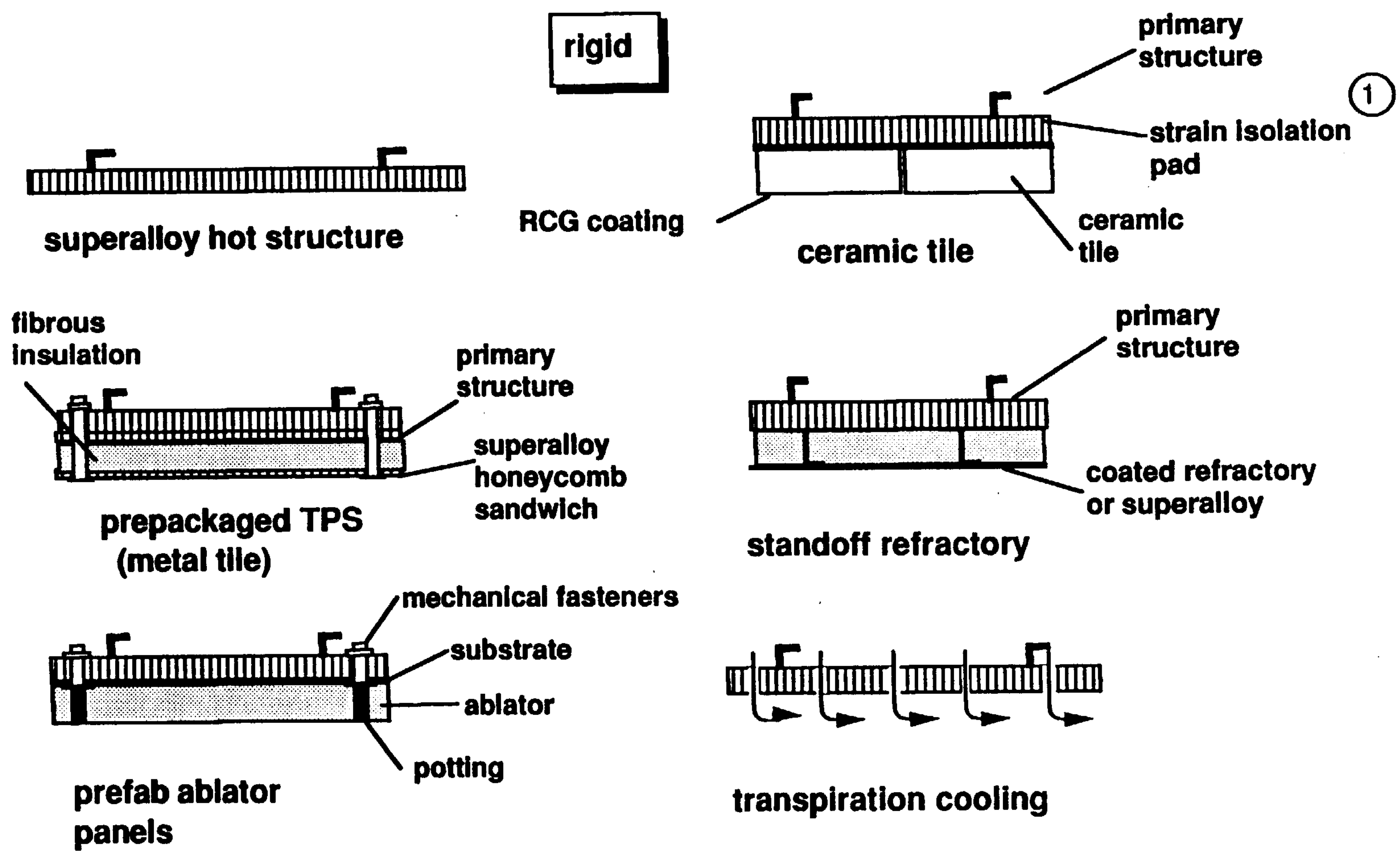


Figure 9.2-12 Trajectory Temperatures for Wedge Configuration



1 may not be required with composite primary structure

Figure 9.2-13 TPS/Structural Concepts

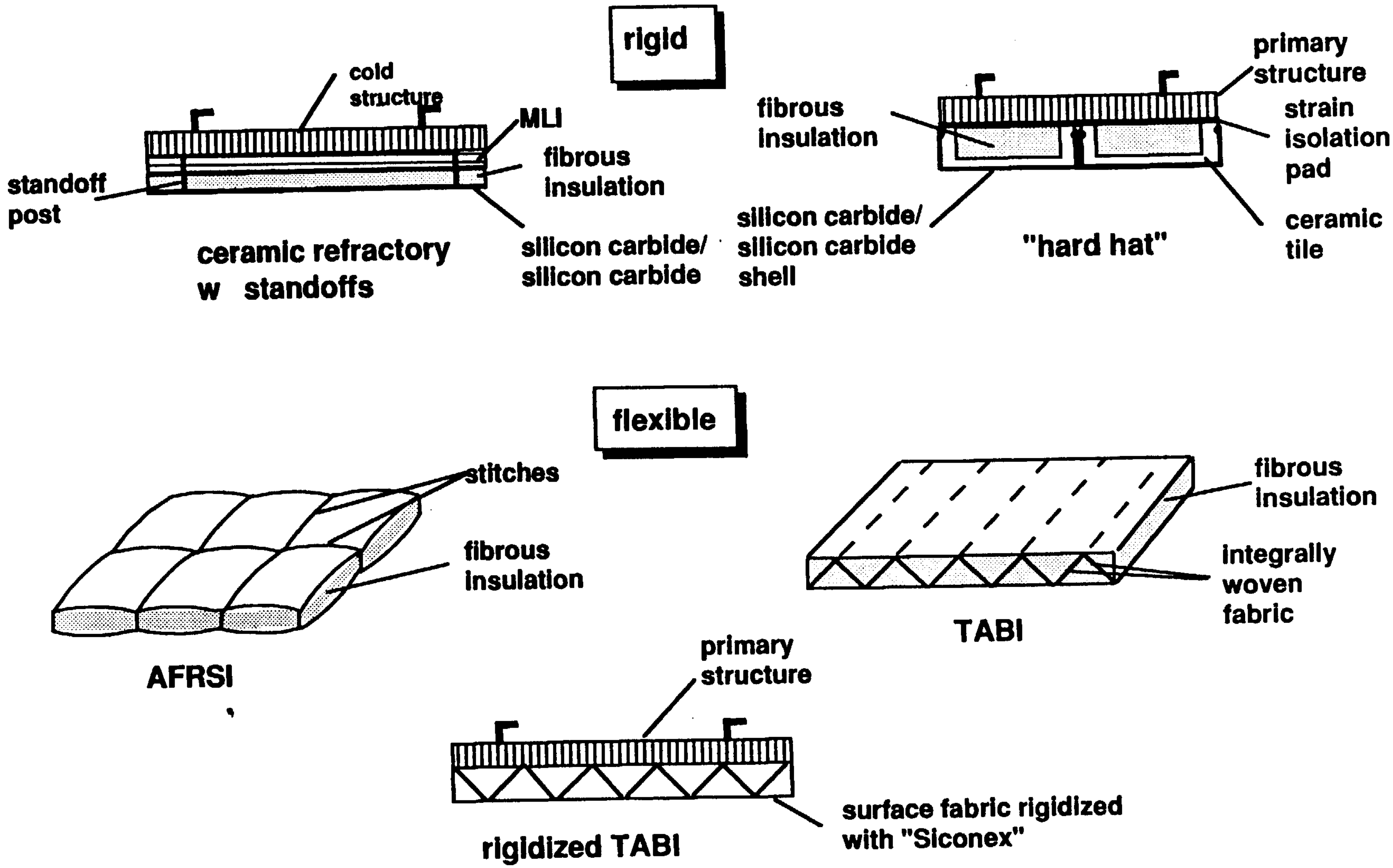


Figure 9.2-13 (continued) TPS/Structural Concepts

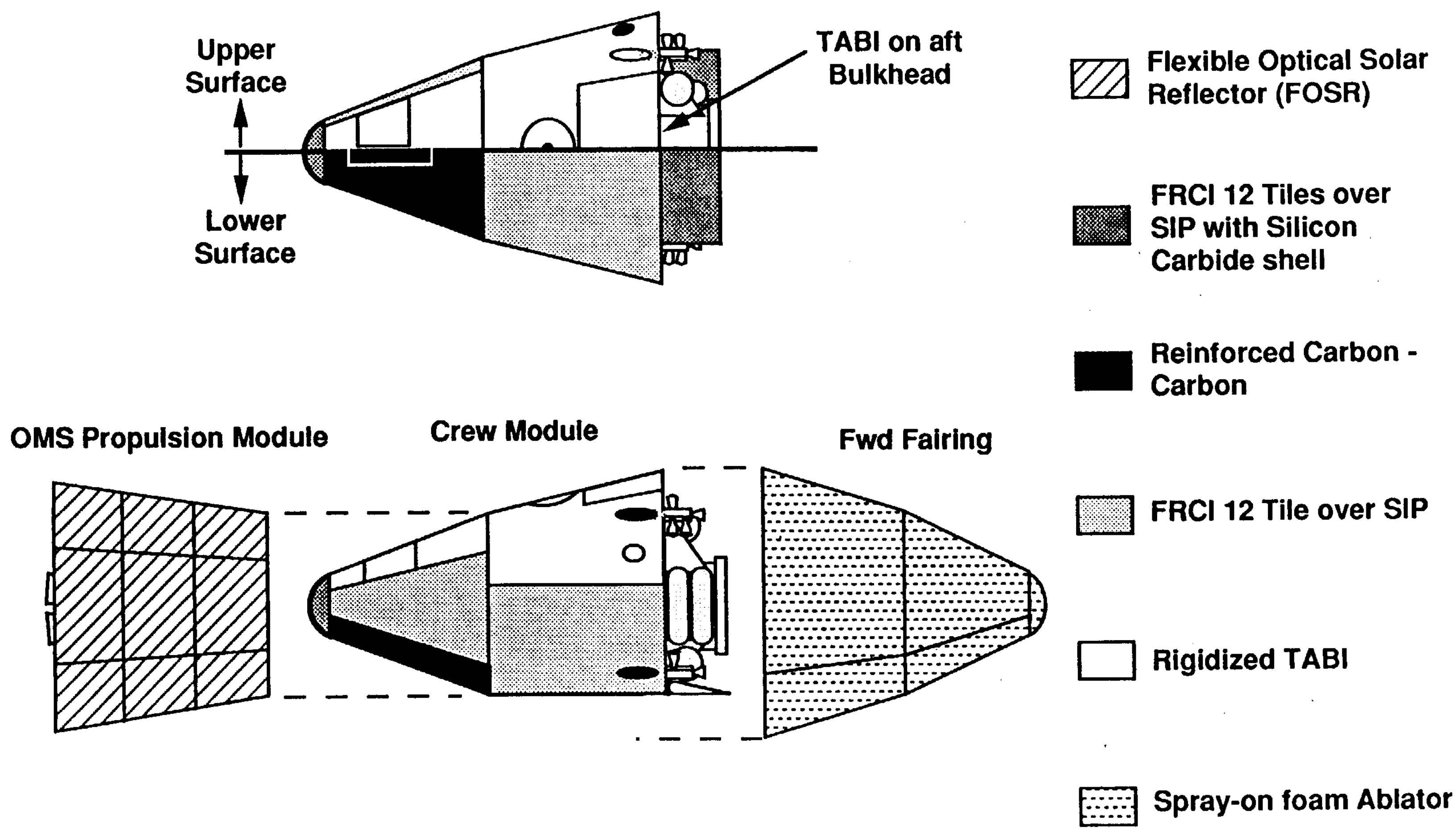


Figure 9.2-14 PLS External TPS Concept

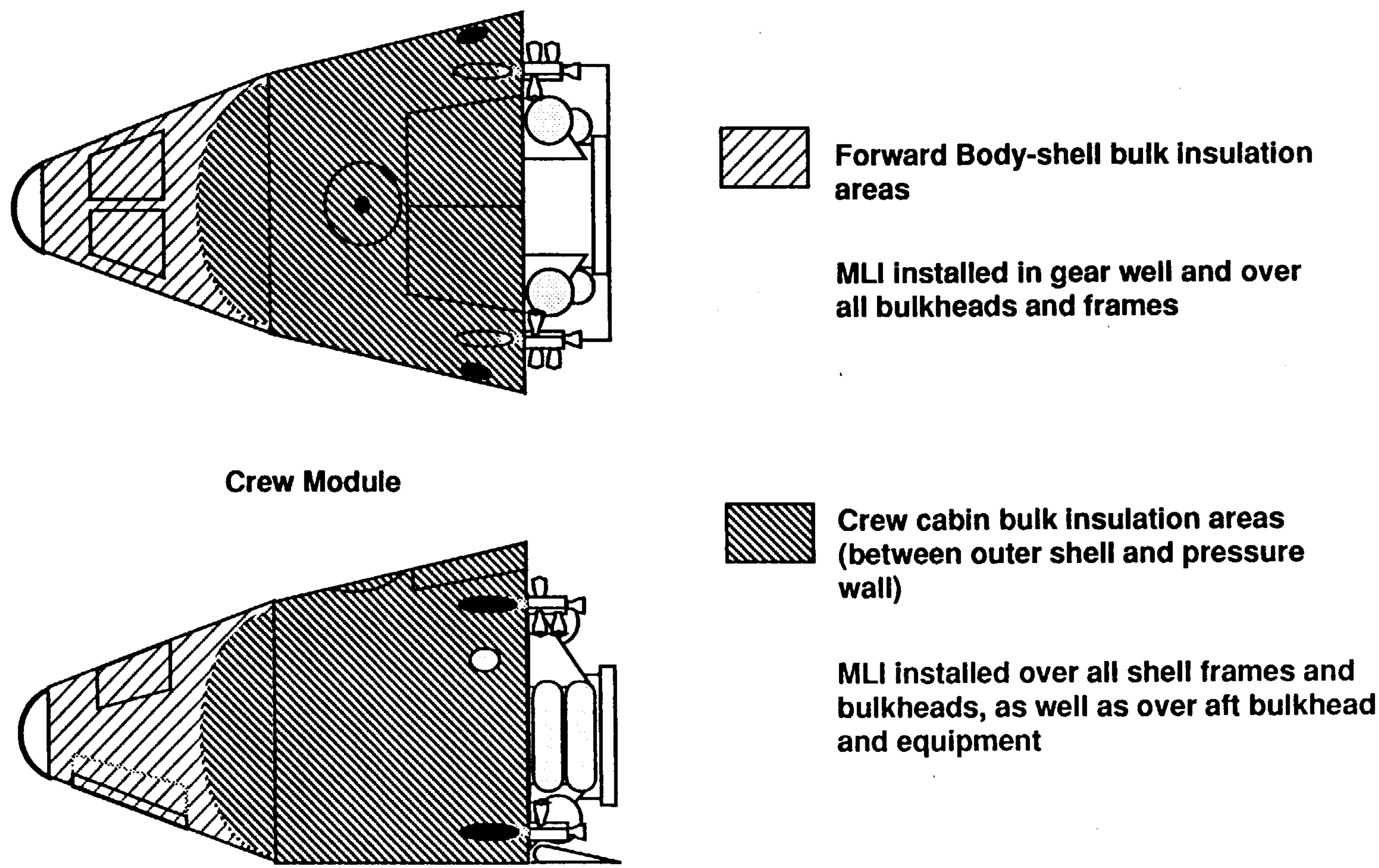


Figure 9.2-15 PLS Internal Thermal Protection Concept

Table 9.2-2 Protection System Equipment List

WBS	ITEM	CREW ROTATION WEIGHT (LB)	DESCRIPTION	MATERIAL
	EXTERNAL TPS	919		
	NOSE CAP	157	S= 13.0 SF	Reinforced C-C
	BODY TPS, ZONE 2	161	S=61 SF	FRCI-12 / SiC
	LANDING PAD DOOR TPS	17	S=6 SF, incl closeouts	FRCI-12 / SiC
	BODY TPS, ZONE 3	399	S=283 SF	FRCI-12
	BODY TPS, ZONE 4	81	S=155 SF	Rigid TABI
	ACCESS PANEL TPS	17	S= 32 SF	Rigid TABI
	PARACHUTE COVER TPS	13	S=24 SF	Rigid TABI
	AFT BULKHEAD TPS	74	S=184 SF	Rigid TABI
	INTERNAL INSULATION / TCS	220		
	BULK INSULATION - FWD BODY	43	S= 124 SF	Fibrous Batt
	MULTI-LAYER INSULATION - FWD BODY	9		DG-Kapton
	BULK INSULATION - CABIN	140	S= 401 SF	Fibrous Batt
	MULTI-LAYER INSULATION - CABIN	28		DG-Kapton
	PURGE AND VENT SYSTEM	63	SCALED FROM SHUTTLE	ALUMINUM
	DUCTING	30		
	VALVES	20		
	SUPPORT, INSTALLATION	13		
	WINDOW / HATCH CONDITIONING	19	SCALED FROM SHUTTLE	
	PLUMBING	7		
	DESSICANT, VALVES, DISCONNECTS	8		
	SUPPORT, INSTALLATION	4		
	METEOROID / RADIATION PROTECTION	0	PROVIDED BY STRUCTURE	
1.1.4	**PROTECTION - CREW MODULE**	**1220**		
1.1.4	**PROTECTION - OMS MODULE**	**71**	S=792 SF	FOSR
1.6.4	**PROTECTION - FORWARD FAIRING**	**239**	S= 796 SF	SPRAY-ON FOAM

9.3 Propulsion

The PLS must perform a variety of maneuvers requiring propulsive thruster firings. The required energy, as well as the most desirable thrust level, for the different types of maneuvers vary over orders of magnitude. This leads to the requirement to carry a large, orbital maneuvering system (OMS), a reaction control system (RCS) for multiaxis orientation, and a small proximity operations system for precise, terminal maneuvers. Each system is addressed separately although the control jet selection logic relies on a highly integrated approach between all propulsive and aerodynamic surface controls.

9.3.1 Orbital Maneuvering System (OMS)

9.3.1.1 System Sizing

The OMS has two main functions. The first is to raise and/or circularize the PLS altitude to achieve the desired orbit after separation from the launch vehicle. The second function is to provide the deorbit burn to initiate reentry.

The energy required, or ΔV, varies according to the desired final orbit. In the original statement of work, it was assumed the launch vehicle would deliver the PLS to a 50 by 100 nmi orbit at a 28.5° inclination. This orbit was later changed to a 80 by 150 nmi orbit which is more representative of the delivery orbits planned for the ALS-type launch vehicle envisioned for PLS use.

The differences in required propellant quantity is not so significant that the tanks cannot be sized for the largest ΔV requirement of 537 ft/sec. In addition, a deorbit burn requires 384 ft/sec. Adding a 10% reserve for contingency/growth, the tankage is sized for a ΔV of approximately 1000 ft/sec.

The engines for the OMS must provide just enough thrust to sufficiently accelerate the PLS in a reasonably short time. A three engine configuration is a good compromise for providing engine-out capability while keeping individual thruster size small. Using a 5% thrust to weight ratio with two engines in operation (one engine out) yields an engine thrust level of around 800 lbf per engine.

9.3.1.2 Propellant Selection

The choice of propellants is based on several factors. A ranking of propellant options was performed to account for safety, performance, and cost issues. These rankings, being somewhat subjective, were performed by several propulsion personnel and were then subjected to a sensitivity analysis to ensure an unbiased answer.

The objective of working with near term technology implies that new or exotic propellant systems would not be appropriate for consideration. The choices examined, as shown in Figure 9.3.1.2-1, all represent proven technology solutions (in many cases, hardware exists at the required size). The average "raw scores" for material properties is shown as Table 9.3.1.2-1. These numbers were then put into a spreadsheet which multiplied the scores by the perceived relative importance of each issue. These relative percentages (called "weighting factors"), as seen on Table 9.3.1.2-2, were varied to see if the answer (relative winner) might change. In fact, other prioritizations of the issues (spreadsheets not shown) resulted in the same answer: liquid oxygen (LOX)/RP-1 (kerosene) followed closely by hydrogen peroxide (H_2O_2)/RP-1 were the preferred choices. A comparison of system weight and volume is shown in Figure 9.3.1.2-2.

9.3.1.3 System Description

As is explained in Section 9.11, the OMS is a fully expended system, jettisoned along with the radiator after the deorbit burn is completed. The system schematic for the OMS is shown in Figure 9.3.1.3-1 and allows for fail-op, fail-safe operations. Note that the RCS can be used in an emergency to effect a reentry. The OMS equipment list is shown as Table 9.3.1.3-1.

9.3.2 Reaction Control System (RCS)

9.3.2.1 System Sizing

The RCS is sized to provide attitude control and limited forward and aft velocity changes for a variety of orbital and reentry maneuvers. Unlike the OMS, where a few discreet burns are made between known spatial locations, the RCS is used differently on each mission. This requires the system capacity to be sized for a reasonable "worst case" mission scenario.

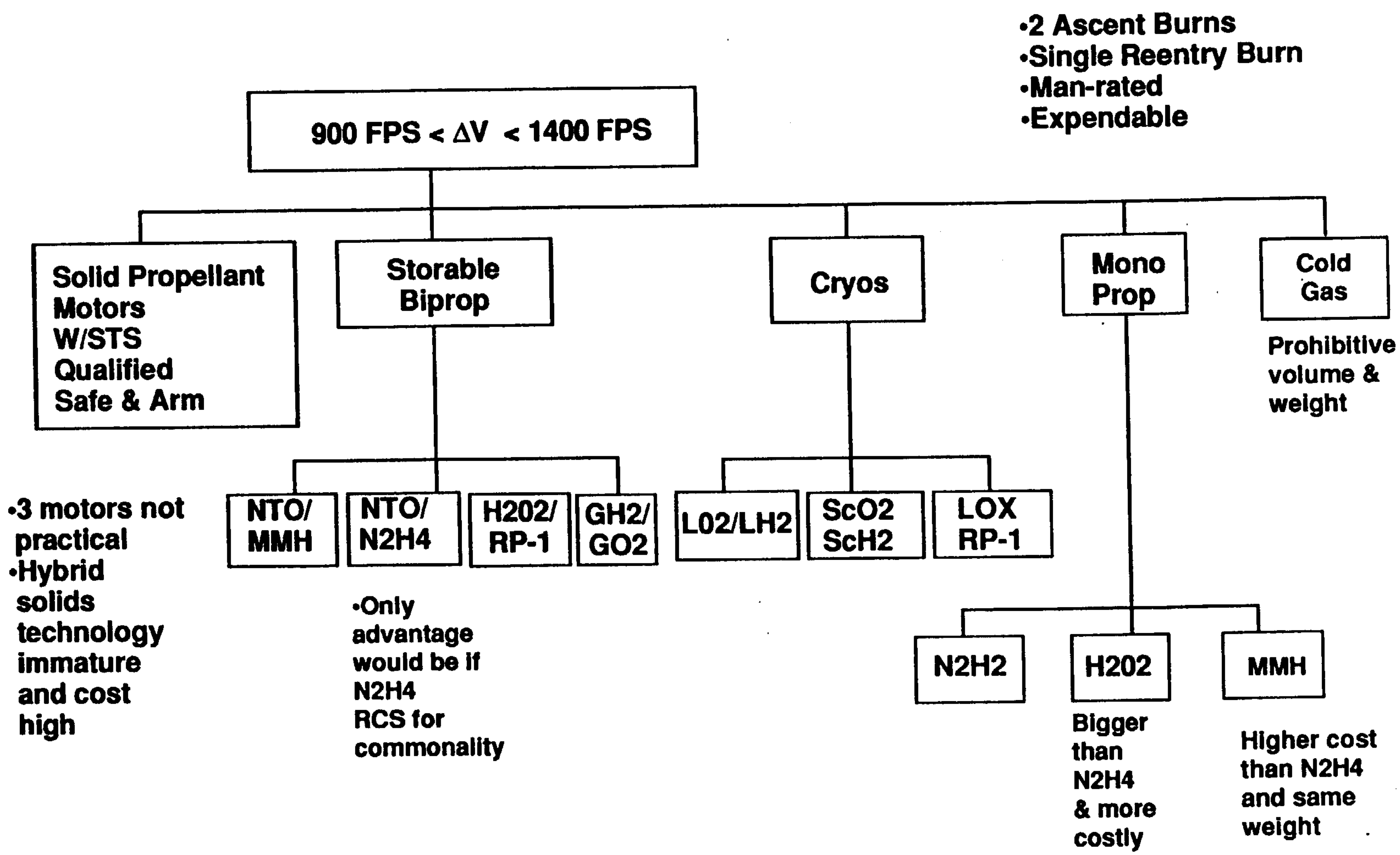


Figure 9.3.1.2-1 OMS Propellant Options

Table 9.3.1.2-1 OMS Propellant Scoring

Selection/Criteria	Storables				Cryogens		
	NT0/ MMH	H202/ RP-1	N2H4	G02/ GH2	L02/ RP-1	L02/ LH2 Cryo. Eng	L02/ LH2 Stor. Eng.
1. Crew Safety	3	8	5	10	7	5	6
2. Cost (LCC)							
a. RDT&E	10	4	9	6	9	5	6
b. Recurring	8	6	9	10	9	4	6
c. Operations	3	8	4	8	6	5	6
3. Weight	10	8	4	7	10	8	6
4. Volume	9	10	7	1	9	5	4
5. Reliability							
a. Ignition	10	8	10	7	6	6	6
b. Complexity	5	7	10	9	8	4	3
6. Ground Operations	2	9	4	6	8	7	6
7. Technical Maturity/Risk	10	7	10	8	8	5	4
8. Maintenance	4	7	6	10	8	7	5
9. Contamination at Space Station	2	6	7	9	4	9	9

Table 9.3.1.2-2 OMS Weighting Factors

OMS PROPELLANT SELECTION MATRIX- SEVEN OPTIONS AND NINE SELECTION CRITERIA								
CRITERIA	WT FACTOR	NTO/MMH	H202/RP-1	N2H4	GO2/GH2	LO2/RP-1	LO2/LH2	ScH2/ScO2
crew safety	25	7.5	20	12.5	25	17.5	12.5	15
cost(LCC)	15	10.5	9	11	12	12	7	9
a.RDT&E		10	4	9	6	9	5	6
b.recurring		8	6	9	10	9	4	6
c.operations		3	8	4	8	6	5	6
weight	15	15	12	6	10.5	15	12	9
volume	13	11.7	13	9.1	0	11.7	6.5	5.2
reliability	10	7.5	7.5	10	8	7	5	4.5
a.ignition		10	8	10	7	6	6	6
b.complexity		5	7	10	9	8	4	3
ground ops	8	1.6	7.2	3.2	4.8	6.4	5.6	4.8
tech. maturity	7	7	4.9	7	5.6	5.6	3.5	2.8
maintenance	4	1.6	2.8	2.4	4	3.2	2.8	2
contam. at SS	3	0.3	1.8	2.1	2.7	1.8	2.7	2.7
TOTAL SCORE	100	62.7	78.2	63.3	72.6	80.2	57.6	55

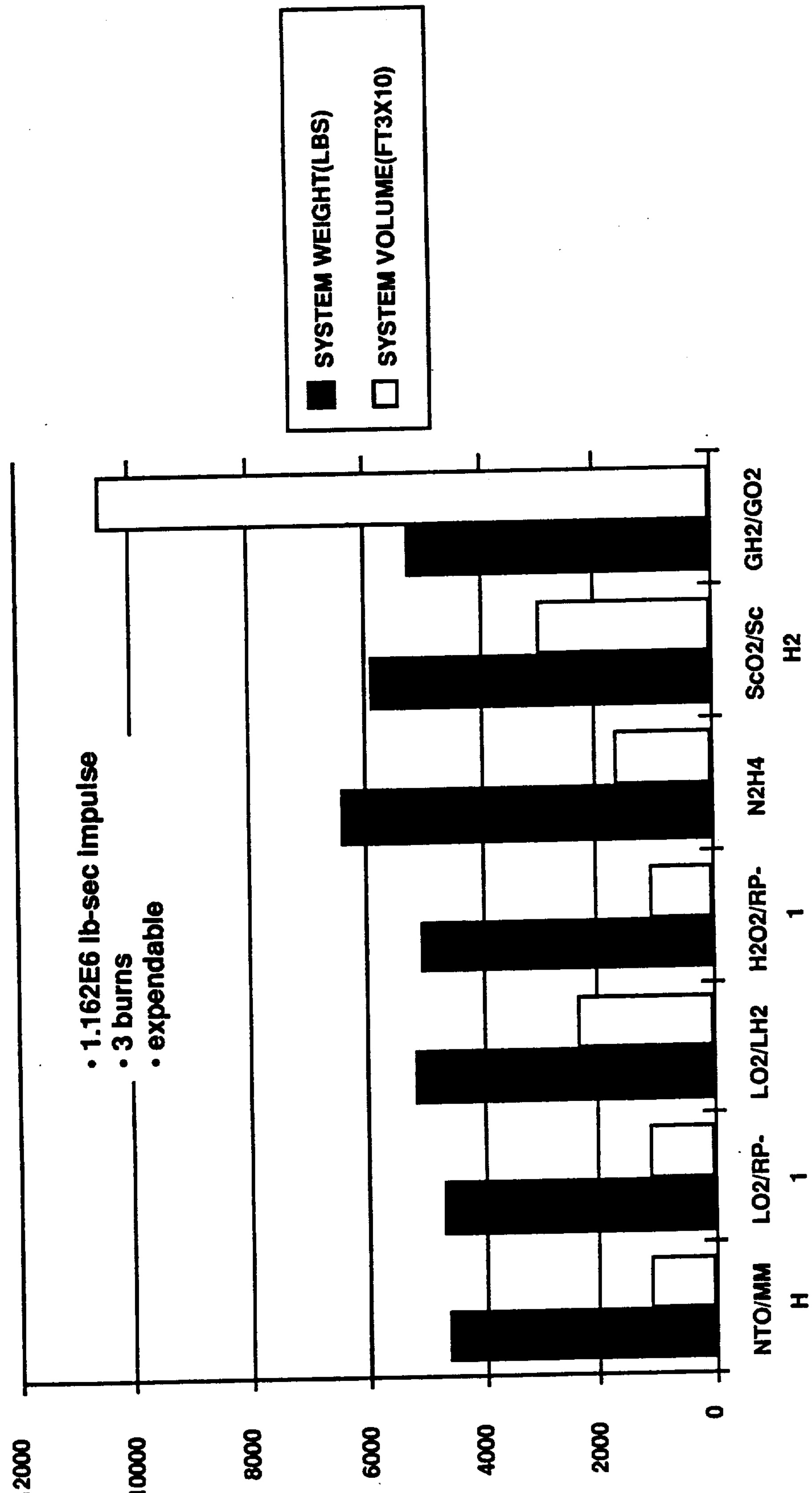


Figure 9.3.1.2-2 OMS Size For Selected Propellant Combinations

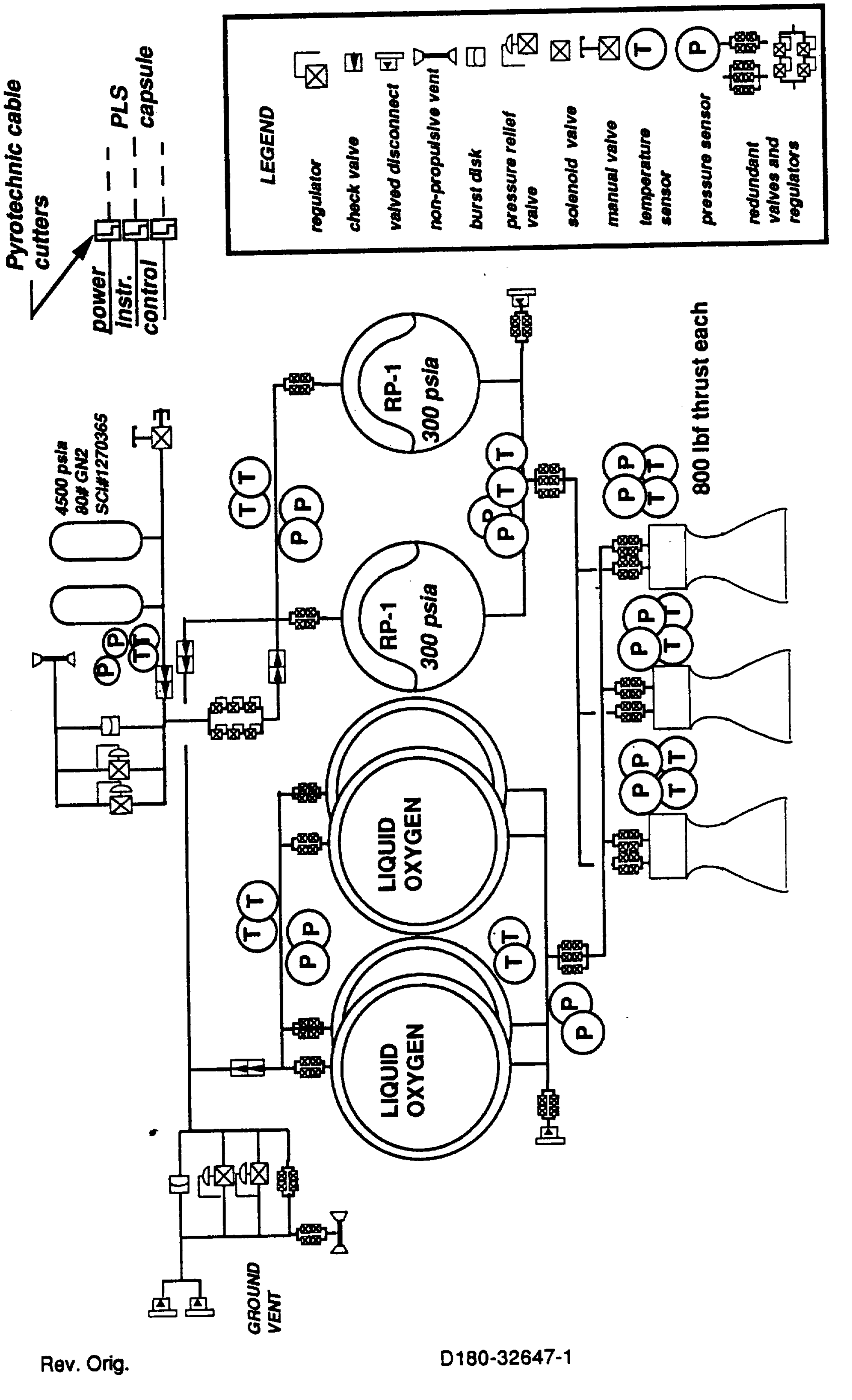


Figure 9.3.1.3-1 Man Rated PLS OMS Schematic

Table 9.3.1.3-1 OMS and LES Equipment List

WBS	ITEM	QTY	Hardware Wt. (lb)	Prop. Wt (lb)	Pk. Pwr. Watts	SUPPLIER	HERITAGE
	Engines / Mounts	3	165		3000		
	Propellant Supply - OMS		692				
	Tankage - LO2	2	93	3267	5		
	Tankage - RP	2	115	1445	5		
	Fluid Valves - OMS	12	48		180		
	Fluid Valves - LES	2	40		180		
	Manifold	2	233				
	LES Disconnects		24				
	Tank Fill, Drain &Vent		48				
	Propellant Supply Support		91		5		
	Pressurization System		209				
	GN2 Bottle(s) - OMS	2	128	107	5		
	Gas Valves	4	18		60	MOOG	
	Regulators	2	9			Fairchild	
	Fill & Drain Disconnects	2	2			Pyronetics	
	Manifold/Plumbing		10				
	Bottle Vent / Relief		17			Fairchild	
	Press Sys Support		25		5	Boeing	
1.6.6	**Propulsion - OMS Module**		**1066**	**4819**	**3445**		
	Turbopump assembly		1140			RS 27 Derivative	
	Engine / Engine mount		270			Hydrazine Gas Generator	
	Gas Generator, Tank, and Fuel		360				
	LES Manifold, plumbing		101				
	LES Support, Installation		187				
	Launch Escape System		**2058**				

As a study input, the satellite servicing missions (the most demanding from a maneuvering standpoint) were assumed to require two rendezvous' and two missed attempts. Each attempt is assumed to require a ΔV expenditure of 50 ft/sec for a total ΔV of 200 ft/sec. In addition, thruster firings are required to maintain attitude control upon reentry until the body flap becomes aerodynamically effective.

Including a margin for uncertainty and reserve capability, a total RCS system capacity was assumed of about 350 ft/sec (see Section 9.5).

9.3.2.2 Propellant Selection

The process of selecting the RCS propellants was very similar to the methodology of Section 9.3.1.2. Again safety was factored heavily; in the case of RCS, residual propellants are likely to be present upon landing, and risk to the personnel on board or on the ground should be minimized.

The choices considered are shown in Figure 9.3.2.2-1. The winning combination was H_2O_2/RP-1. The question immediately comes to mind: why not change the oxidizer on either the OMS or RCS and use a common oxidizer/fuel? This, in fact, could be done, but there are reasons why it was not. First, liquid oxygen is a poor choice for the RCS due to boiloff during the longer missions and due to the fact that each RCS thruster would require an ignitor (a reliability issue compared to hypergolic H_2O_2/RP-1). Secondly, handling a larger quantity of hydrogen peroxide (fairly pure and expensive) for the OMS was perceived by some as an added risk. Thirdly, since the expendability trades resulted in a throw-away OMS, the systems are physically independent anyway. And finally, for growth missions where significantly more OMS performance was required, a higher Isp combination (in this case LOX/RP-1) would be desirable.

9.3.2.3 System Description

A system schematic for the RCS is shown in Figure 9.3.2.3-1 and the equipment list is shown as Table 9.3.2.3-1. The thrusters are arranged in four clusters and provide redundant capability in all three axis. Two roll thrusters were moved from the "lower" thruster quadrant to the "upper" quadrant to avoid firing into the body flap. The thrusters facing towards the "pointed" end of the vehicle are conformally mounted and fire slightly outward through a cutout in the external skin.

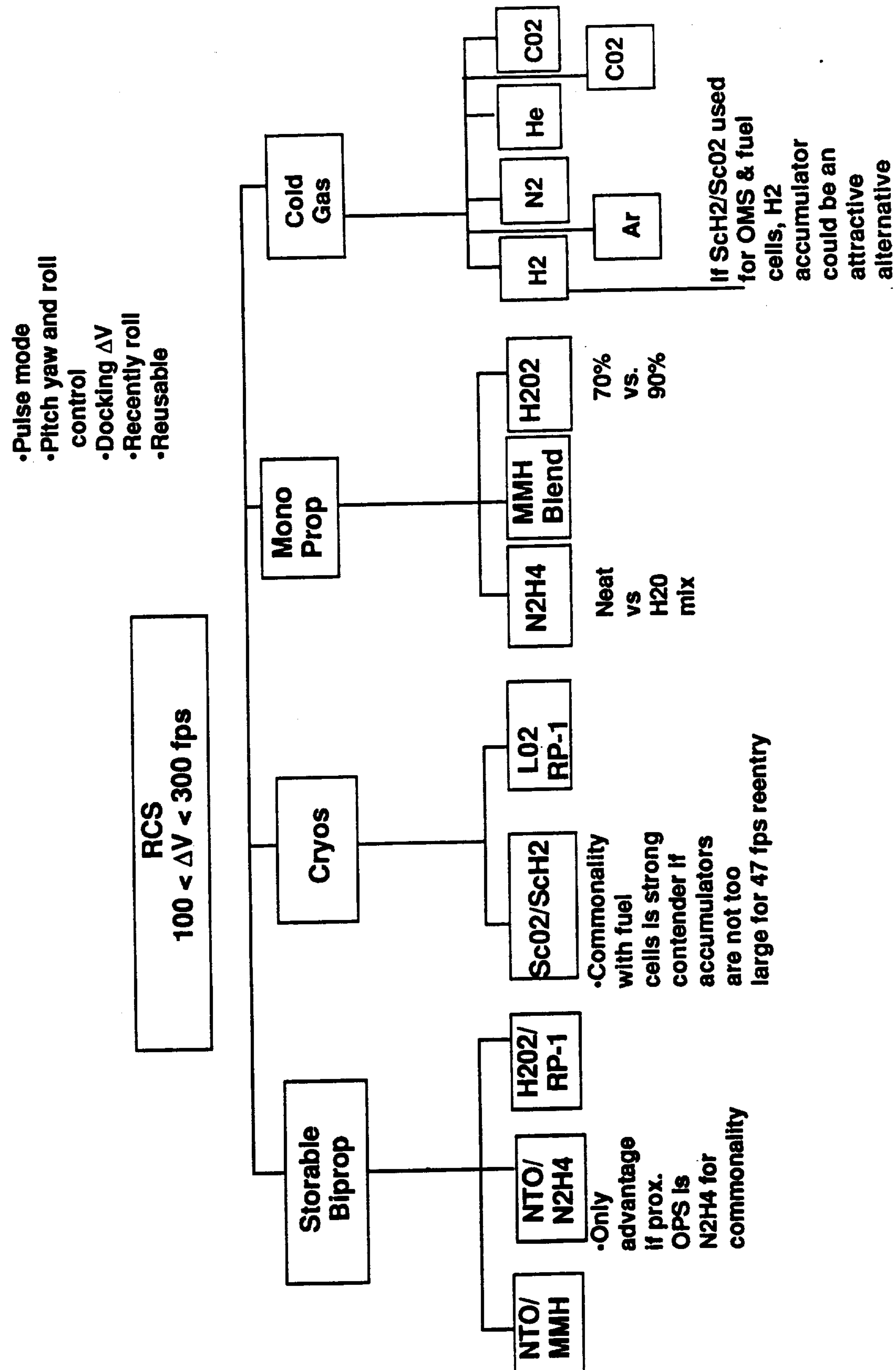


Figure 9.3.2.2-1 RCS Propellant Options

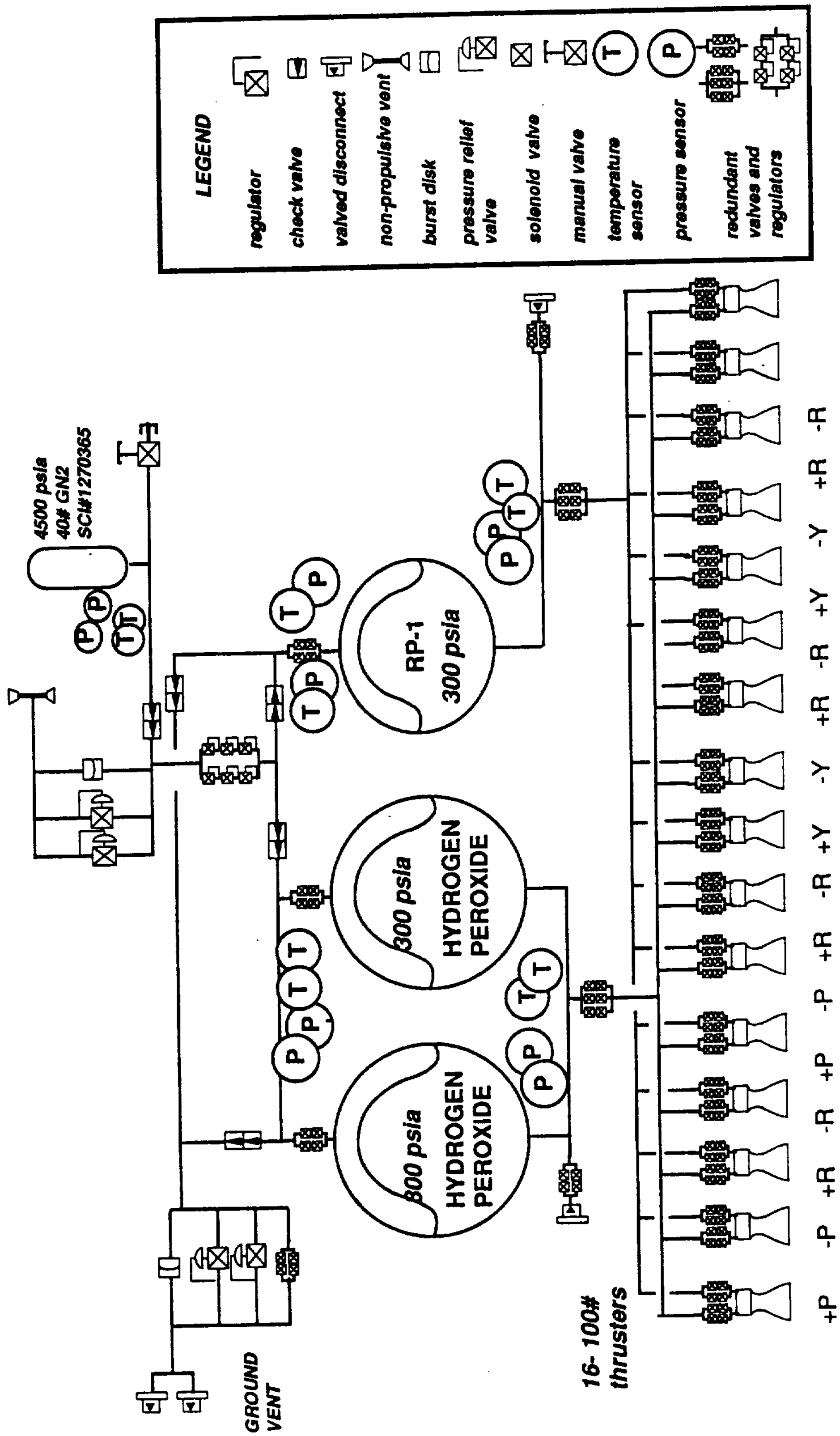


Figure 9.3.2.3-1 Man Rated PLS RCS Schematic

Table 9.3.2.3-1 RCS and Proximity Operations System Equipment List

WBS	ITEM	QTY	Hardware Wt. (lb)	Prop. Capac	Pk Pwr Watts	SUPPLIER	HERITAGE
	Thruster Modules		196				
	Thrusters - RCS	16	133		448	100 lbf thrust each (12 scarfed)	
	Thrusters - Cold Gas	12	45		360	Moog 5264 (30 lbf)	Agena / P-72
	Thruster Module Support	4	18				
	Pressurization System		66				
	GN2 Bottle - RCS	1	28	35	5		
	Regulators	2	9			Fairchild	STS / RCS
	Fill & Drain Disconnects	1	1			Pyronetics	IUS / RCS
	Manifold/Plumbing		10			Boeing	IUS / RCS
	Tank Vent / Relief		9			Boeing	IUS / RCS
	Press Sys Support		9		5		IUS / RCS
	Propellant Supply - Rcs		193				
	Tankage - H2O2	2	60	1074	4		
	Tankage - RP	1	15	143	4		
	Valves	9	35		270	Consolidated Controls	STS / RCS
	Manifold/Plumbing		40			Boeing 304L SS	IUS / RCS
	Tank Fill, Drain & Vent	2	25			Boeing	IUS / RCS
	Propellant Supply Support	4	18			Boeing	IUS / RCS
	Propellant Supply - Cold Gas		517				
	N2 Bottle(S) - Cold Gas	4	310	418	5		Centaur
	Valves	16	82		600	Consolidated Controls	STS / RCS
	Disconnects	5	6			Pyronetics	IUS / RCS
	Manifold/Plumbing		42			Boeing 304l SS	IUS / RCS
	BottleVent / Relief		14			Boeing	IUS / RCS
	Cold Gas Supply Supt/Instl		63		5	Boeing	IUS / RCS
1.1.7	**Propulsion - Reaction Control**		**972**	**1670**	**1797**		

9.3.3 Proximity Operations System

9.3.3.1 System Sizing

Proximity operations involve fine, slow speed adjustments in attitude and velocity when the PLS is operating in the vicinity of another spacecraft. As the selected propellant combination should not adversely affect or contaminate the local environment, the available propellant choices tend to have low performance. For this reason, the amount of propellant required could become significant, and the system ΔV requirement should be kept to a minimum.

Based on previous Space Station and OTV studies, a value of 20 ft/sec was selected as the basis for system design. However, any given mission could have no requirement or could require significantly more ΔV capability, and the expendable tankage could easily be added or subtracted as needed.

9.3.3.2 Propellant Selection

The choices for propellants are shown as Figure 9.3.3.2-1. Of this list, gaseous nitrogen was seen as possessing a good balance of cost, safety (inert), and non-contaminating properties and was selected.

9.3.3.3 System Description

Figure 9.3.3.3-1 depicts the proximity operations system schematic. The thrusters and plumbing remain permanently affixed to the aft bulkhead of the PLS, while the number of expendable tanks can be added or subtracted based on the widely differing requirements for proximity operations capability. Refer to Table 9.3.2.3-1 for a list of equipment associated with the proximity operations system.

9.4 Electrical Power System (EPS)

Electrical power is a flight critical subsystem during all phases of flight. The selected EPS must provide adequate, reliable power, even in contingency (abort) operations.

Within the near-term TAD goals, there are sufficient EPS technologies available to meet the requirements for a PLS. The options for power sources include a variety of hardware which is already man rated and flight qualified. Batteries offer a simple,

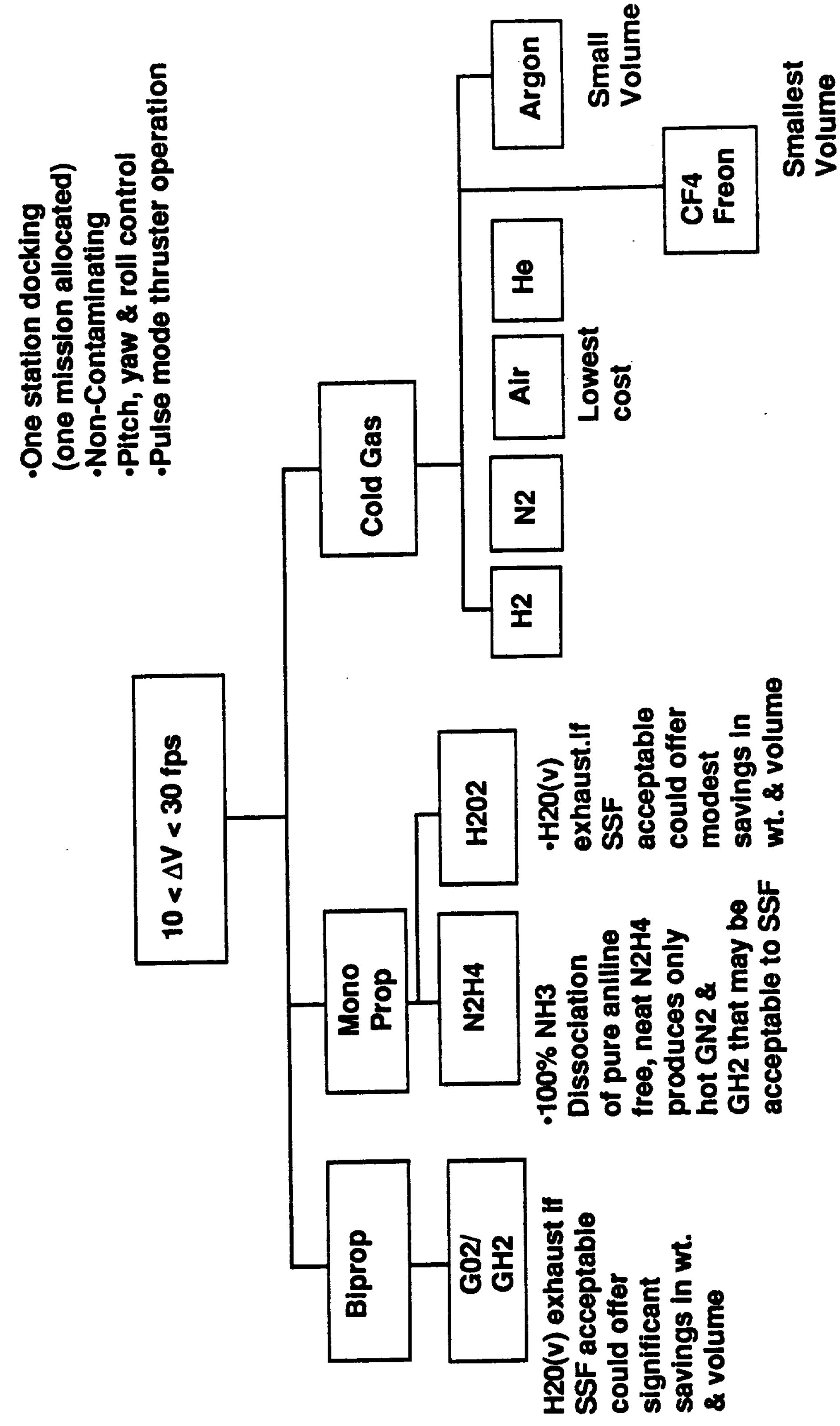


Figure 9.3.3.2-1 Proximity Operations System Propellant Options

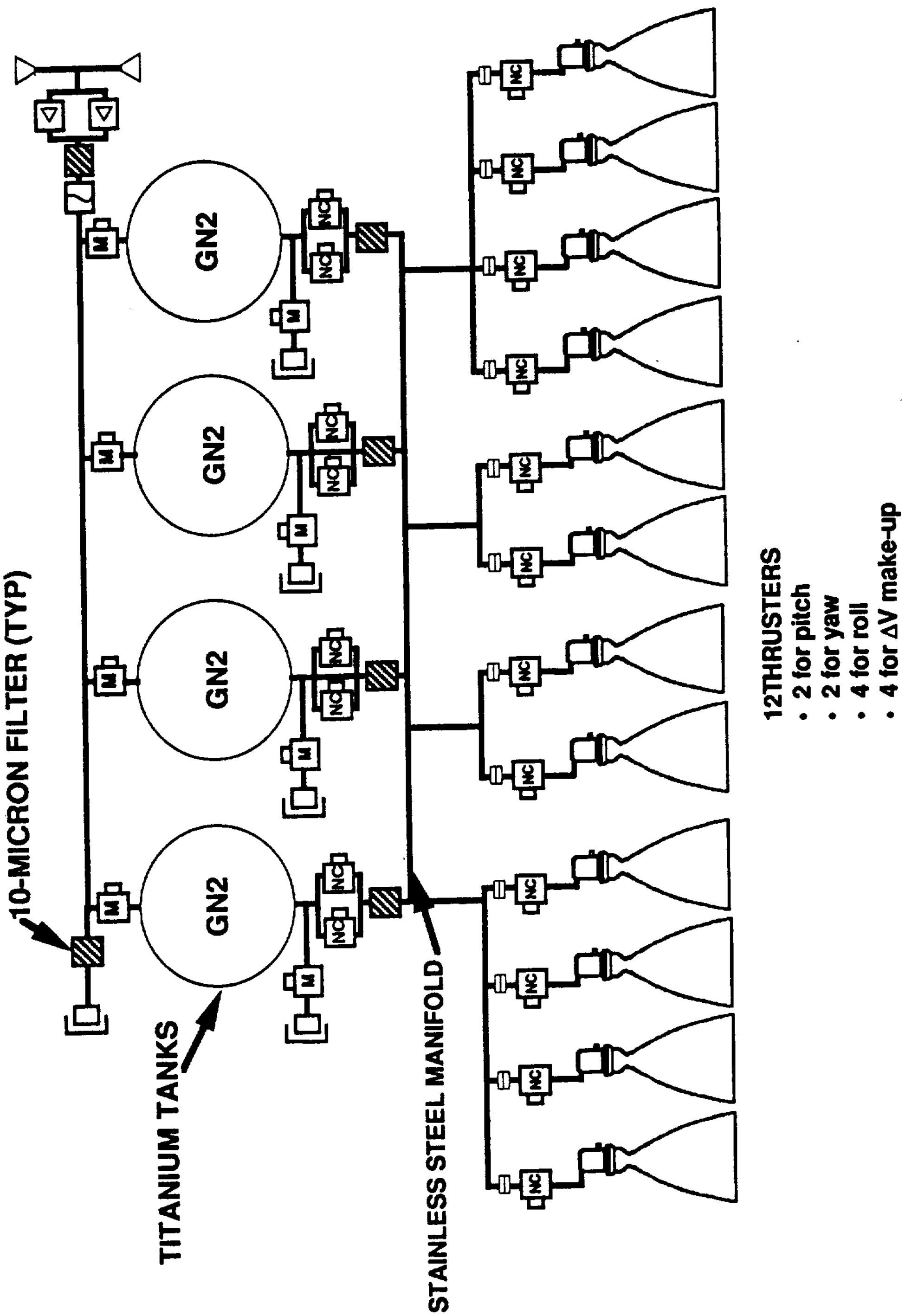


Figure 9.3.3.3-1 Proximity Operations System Schematic

reliable energy source, although the system weight is significant. Solar photovoltaic cell offer a lightweight power source for orbital operations, unfortunately, the highest power loads occur during ascent and descent when the solar array would be useless. Fuel cells and auxiliary power units can provide high power levels at reasonable system weights, but are more mechanically complex. The mission duration and power load profile will ultimately determine the selected EPS concept.

To size the EPS, one needs to consider both the peak demand as well as the total integrated load. For the nominal three day SSF rotation mission, the hardware that is "turned on" or requires power is shown by flight phase in Figure 9.4-1. The resultant power profile is shown in Figure 9.4-2. A key attribute of any successful aerospace program has been the ability of that system to grow with future mission needs. While a battery system might be sufficient for a short duration mission, it was shown in Section 5.1.2 (Figure 5.1.2-1) that the total system weight would quickly become unacceptably heavy for a long duration mission. To accommodate future growth beyond the basic SSF rotation mission, use of a fuel cell system was baselined. There were some concerns, such as the inability to restart a fuel cell inflight and the (unlikely) possibility of a generic defect in the fuel cell assemblies that might precipitate a failure in redundant devices. These concerns led to the decision to retain a battery complement for an independent energy source.

The PLS EPS incorporates a fully redundant architecture plus a third energy source to supply emergency/abort requirements in the unlikely event of failure of both primary sources. The EPS schematic, shown as Figure 9.4-3, shows each fuel cell assembly feeding a separate power distribution panel. Power is distributed to assigned loads from these panels to separate panels. The backup battery feeds both distribution panels upon receipt of "on-line" commands resulting from the initiation of an emergency/abort scenario. In the event of such an occurrence, a defined load reduction would take place to keep the connected load within the battery capacity range. The load panels have each been arbitrarily designed to a requirement for 100 switched outputs of varying current ratings to 10 amps. All switched outputs are baselined to incorporate latching relay devices. Six outputs are assigned to serve the combination of a 10vDC supply, required for the associated fuel cell electronics, and a 115v, 400Hz, 3Ø inverter, required for fuel cell controls and numerous ECLSS functions. The remaining 94 outputs serve as on/off control for assigned loads. As the serviced loads are not envisioned to require high quantities of power on/off cycles,

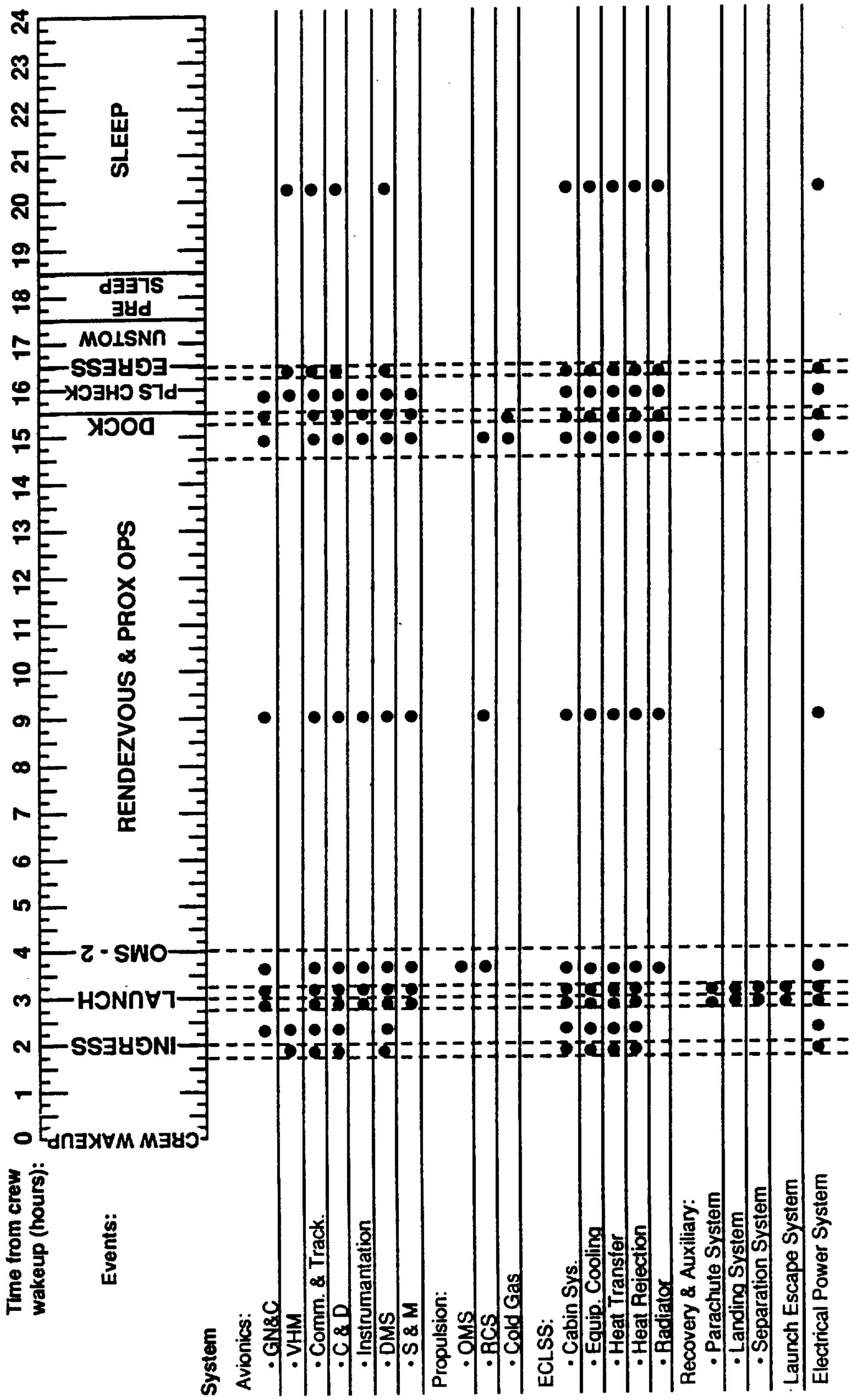


Figure 9.4-1 Active Systems For 72 Hour Mission

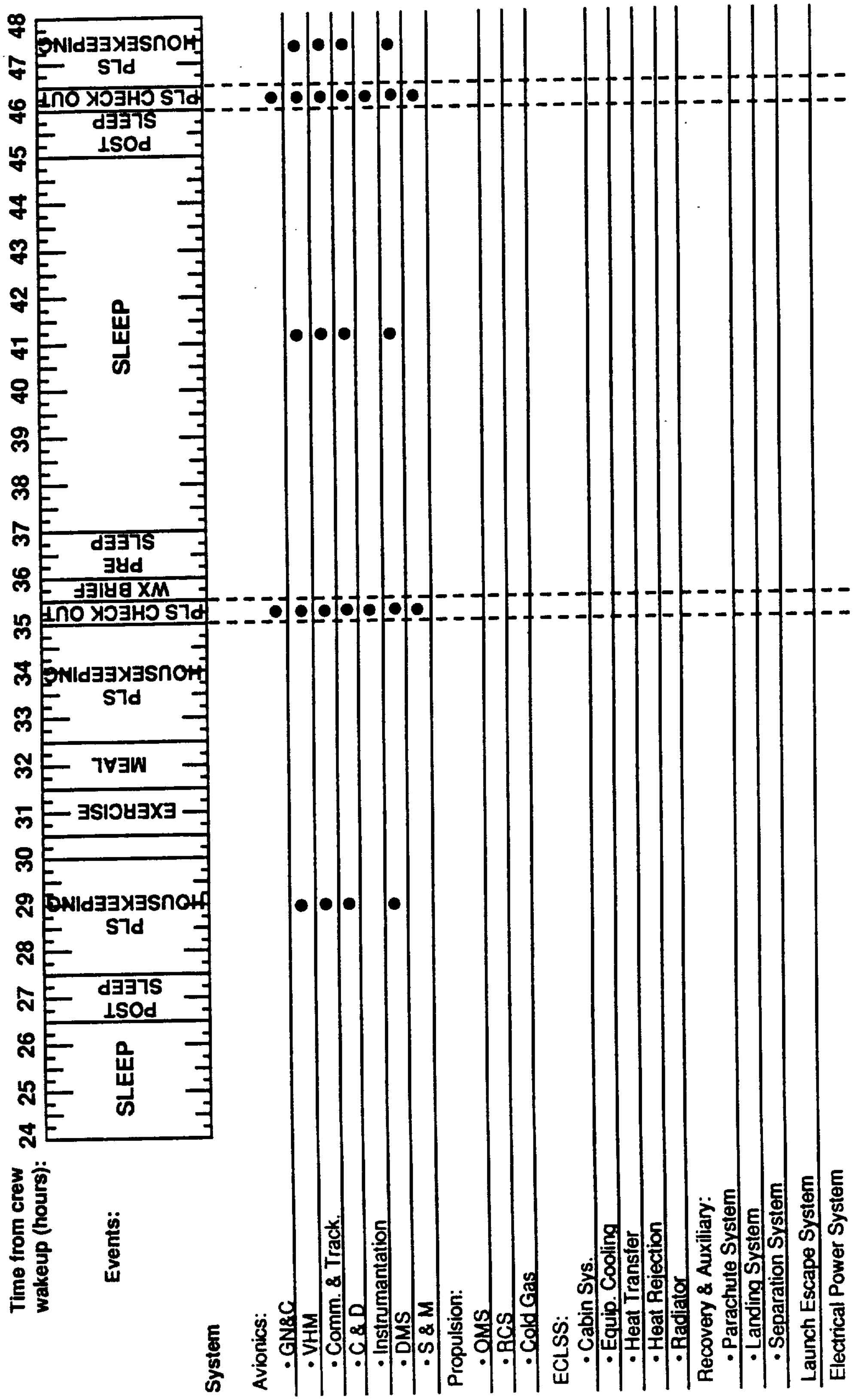


Figure 9.4-1 (continued) Active Systems For 72 Hour Mission

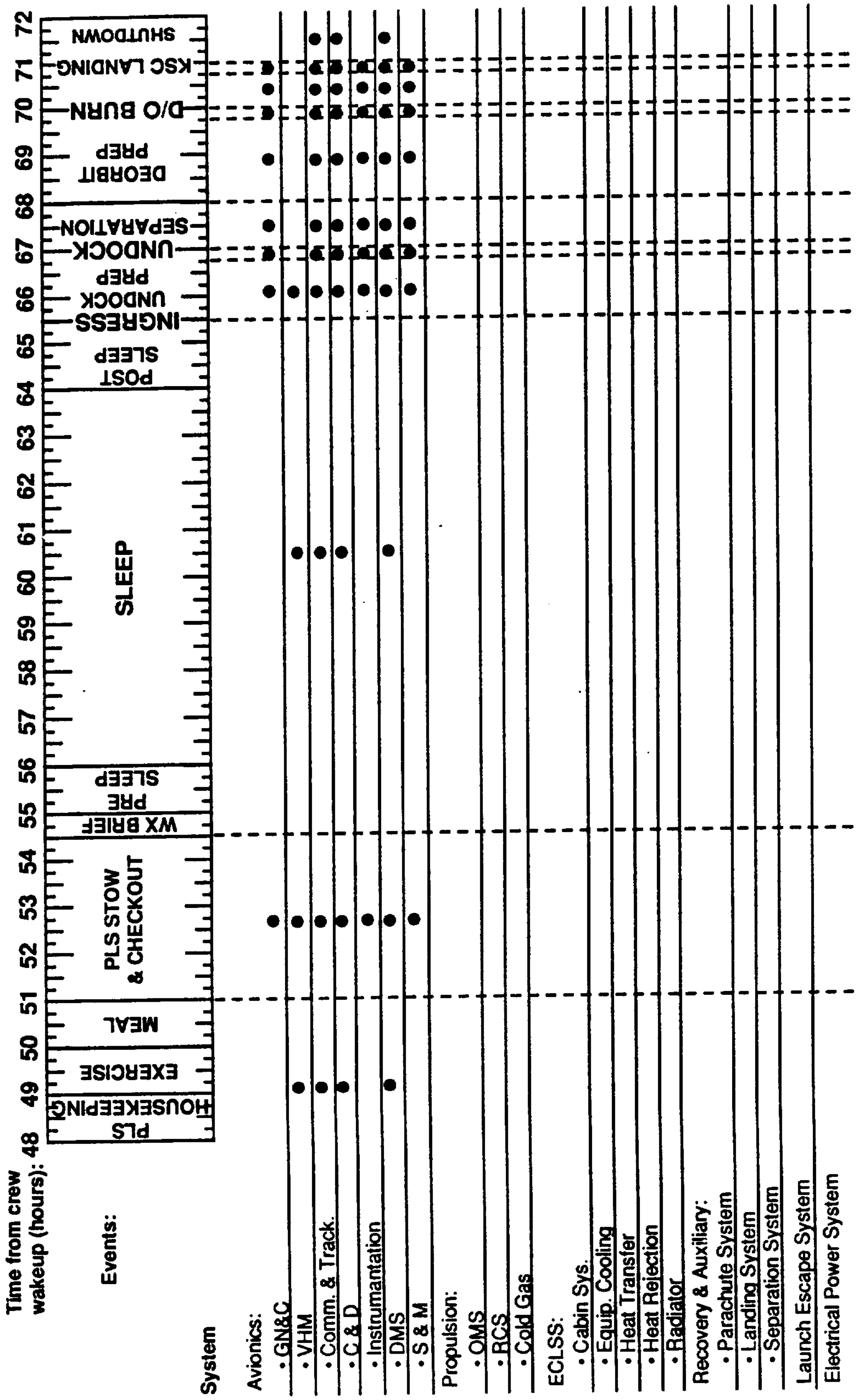


Figure 9.4-1 (continued) Active Systems For 72 Hour Mission

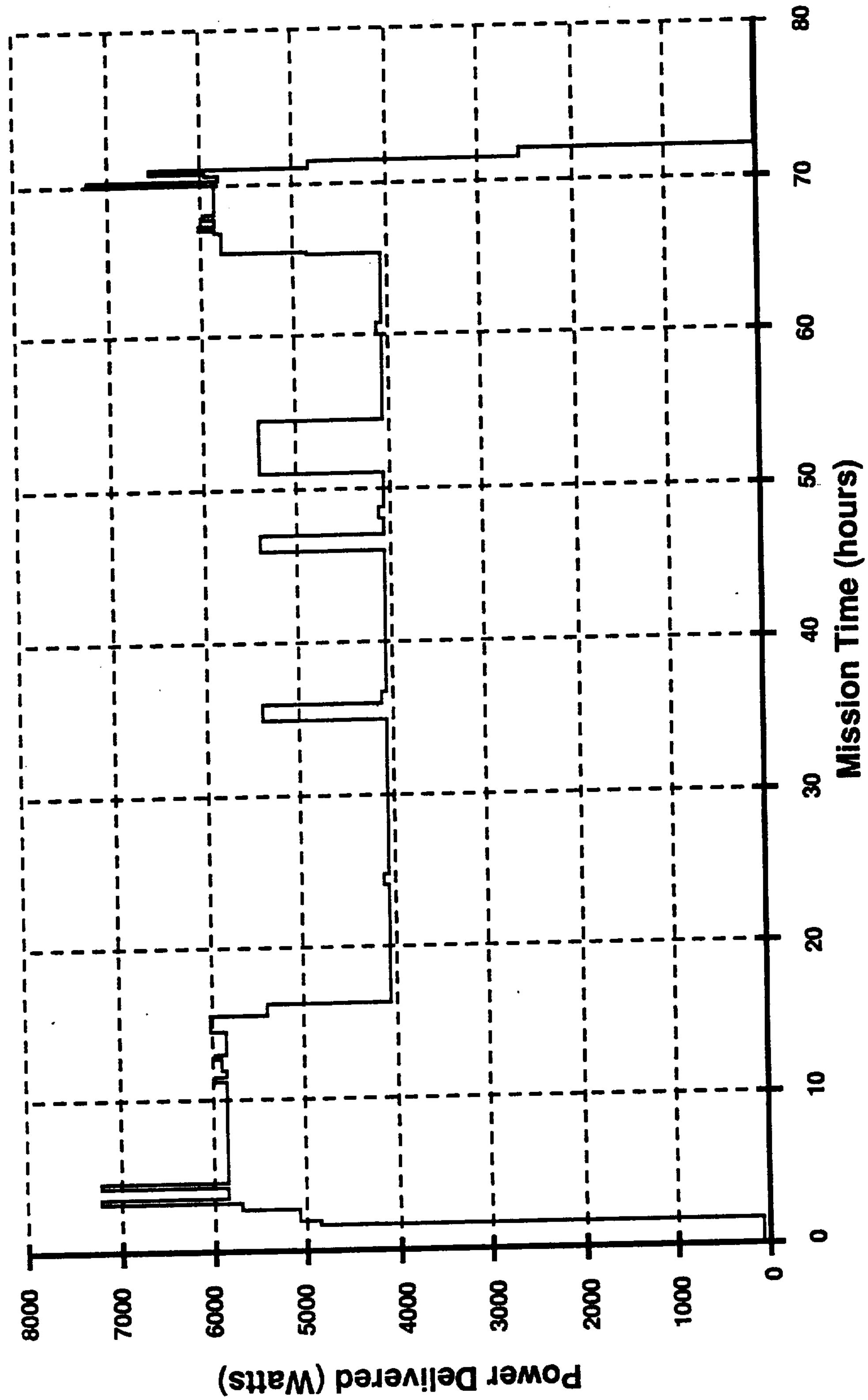


Figure 9.4-2 Power Profile For 72 Hour Mission

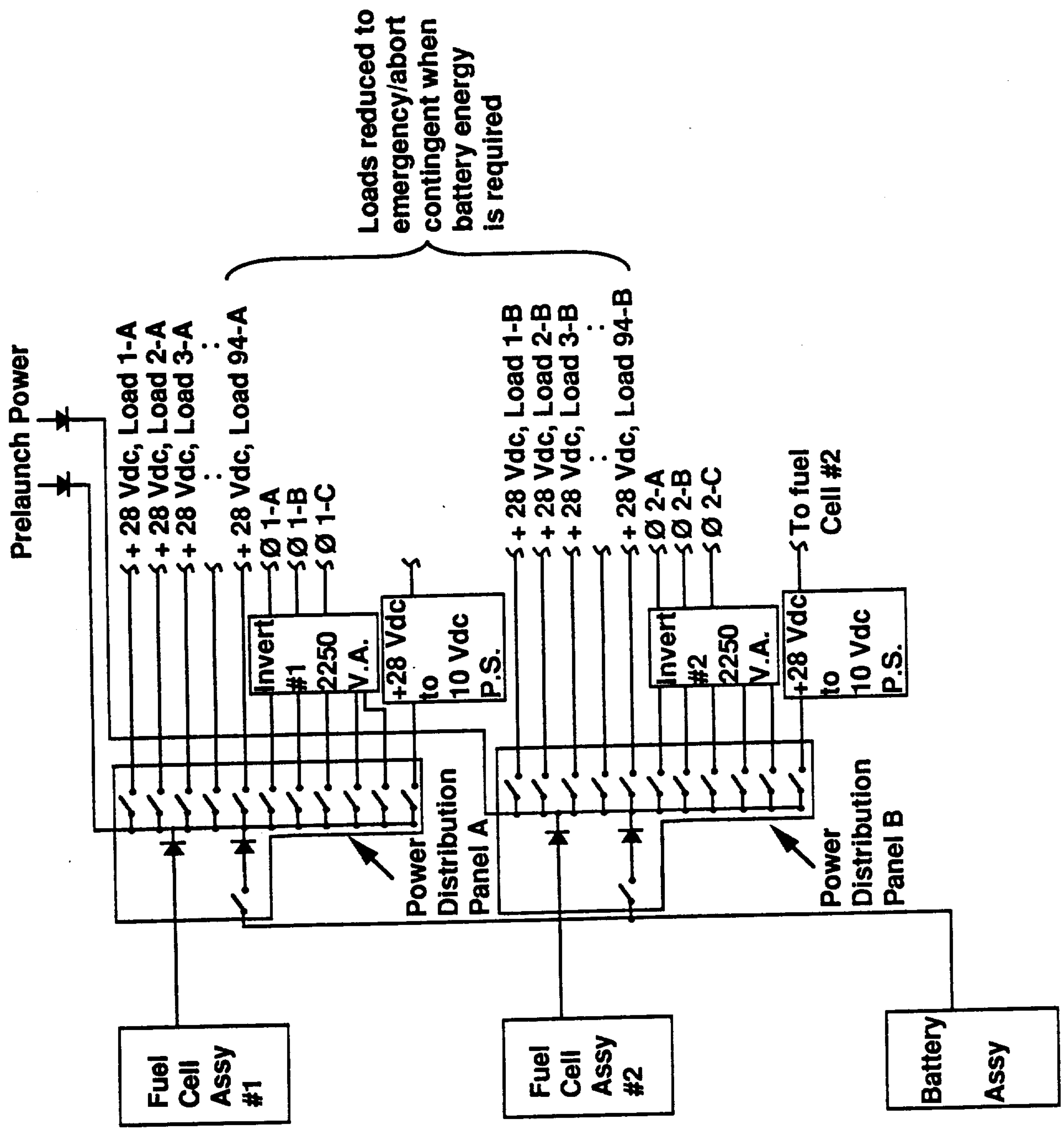


Figure 9.4-3 PLS EPS Architecture

relays with their attendant low continuous series power loss offer a reasonable fit to the assumed requirements. In the event that weight reduction becomes a necessity, the baseline relays and drivers will be traded against solid state devices.

The previously mentioned 10vDC supply and the 115v, 400 Hz, 3Ø inverters complete the EPS component compliment. The 10v supplies will be 180 gram hybrid devices based on Boeing's successful Common Module Power Supply technology. As these devices are quite small, the potential exists to include each supply within its associated distribution panel assembly. A further weight reduction would be achieved in this way since the hybrids would then be designed as unpackaged, plug-in modules. This evaluation will be made as the preliminary design progresses. The 3Ø inverters are presently specified as being the same components employed in the STS. Assuming an even load split, the baseline design loads each inverter to 78% of rating, leaving ample margin for load growth through the use of a qualified design with large attendant cost and schedule savings.

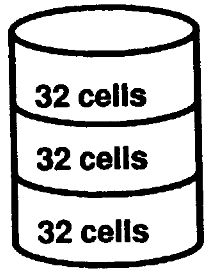
The baseline design embodies the distribution of various voltages in support of defined loads. This has resulted from the adoption of STS or STS-derived equipment for the PLS with attendant cost and schedule benefits. Support for the selected distribution voltages is as follows:

- 28v ± 4vDCRequired by 56% of maximum sustained connected load (Shuttle derived)
- 115v, 3Ø, 400Hz Required by 43% of maximum sustained connected load (Shuttle derived ECLSS and fuel cell controls)
- 10vDC Required by fuel cell controls.

Clearly, redesigning the components that demand over 40% of the connected load power such that they can operate from an unregulated 28vDC bus, as has been proposed for perceived safety reasons, will impose a large (though as yet undefined) cost and schedule impact. The adoption of designed and qualified load and EPS components to the maximum extent practical is considered a major contribution to an optimum PLS design approach.

The primary energy sources are two O_2/H_2 fuel cells derived from the current STS Orbiter design (Figure 9.4-4). The fuel cell system has proven heritage from the STS

- Shuttle fuel cell uses triple redundant fuel cell with 3 stacks of 32 cells each:

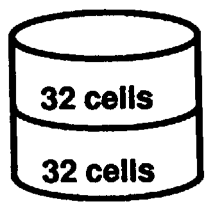
3 x 

28 V	2.33 kw		
28 V	2.33 kw	→	21 kw (36 kw peak)
28 V	2.33 kw		

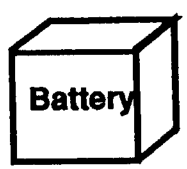
- PLS load requirements:

Sustained load	6.2 kw + 20% margin = 7.4 kw
Peak load:	7.4 kw + 20% margin = 8.8 kw

- Proposed PLS power supply uses dual redundant fuel cells - 2 stacks of 32 cells each - with Li-SOCl2 battery backup:

Nominal: 2 x 

28 V	2.33 kw	→	9.3 kw (16 kw peak)
28 V	2.33 kw		

Contingency: 6 x 

28 V	7.7 kw-hr	→	46.2 kw-hr total (10 hr @ 4.6 kw)

Figure 9.4-4 PLS EPS Sizing Based on STS Hardware

Program. PLS will use the same fuel cell stack, except with two of the 32-cell stacks instead of the three STS uses. The accessory unit associated with the STS fuel cell system will be used directly from STS without modification. Although this system is over designed for PLS (a redundancy factor of 2.5 against the maximum sustained loads and 3.6 against the peak loads) the extra mass associated with the accessory unit is small and qualification of pumps and valves for the lesser mission requirements of PLS does not warrant the redesign costs. The fuel cell stacks are two thirds the length of those used on Shuttle (see Figure 9.4-5). With each 32-cell unit stack being capable of producing 2.33kW, two fuel cells, each consisting of two 32-cell units, will provide 9.3kW nominal and 16kW peak power capability. Since the PLS power requirements are proportionately less than those of Shuttle, only two of the 32-cell unit stacks are needed to produce the required power. For contingency, 6 lithium thionyl chloride batteries will supplement the fuel cells should a fuel cell failure occur. The batteries are capable of producing 4.6 kW for 10 hours. The 4.6kW load is an emergency reduced load to provide essential power for return should the fuel cells fail.

PLS fuel cells will require 24 in. diameter tanks for hydrogen and 20 in. diameter tanks for oxygen. The 3 day mission requires two tanks for each fuel, and the 7 day mission will have four tanks each. For comparison the STS fuel cell system and tank sizes are depicted on this chart. Since the duration for Shuttle is 14 days, the fuel tanks are a larger diameter.

Maintenance of the PLS fuel cells will be more accessible than that previously experienced on Shuttle. The PLS fuel cell systems will be mounted to permit access to frequently maintained components. Fuel cell start up following periods of non-operation have been a problem in the past. Efforts will be made to understand the nature of the start up problem (primarily keeping the wick "wet") and minimize effects on the fuel cell. There are technology studies under way aimed at addressing this issue.

The lithium-thionyl chloride ($Li\text{-}SOCl_2$) batteries were selected for their high energy density and long storage life. These batteries are being space qualified for the Centaur program, with qualification scheduled by mid 1991. The batteries are planned for use as designed, without modification, since the PLS loads are moderate for this battery. The lithium batteries will be mounted to structure to provide the necessary cooling. Since the PLS power requirement is minimal, the excess heat generated during discharge can be absorbed by the battery mass imparting a minor

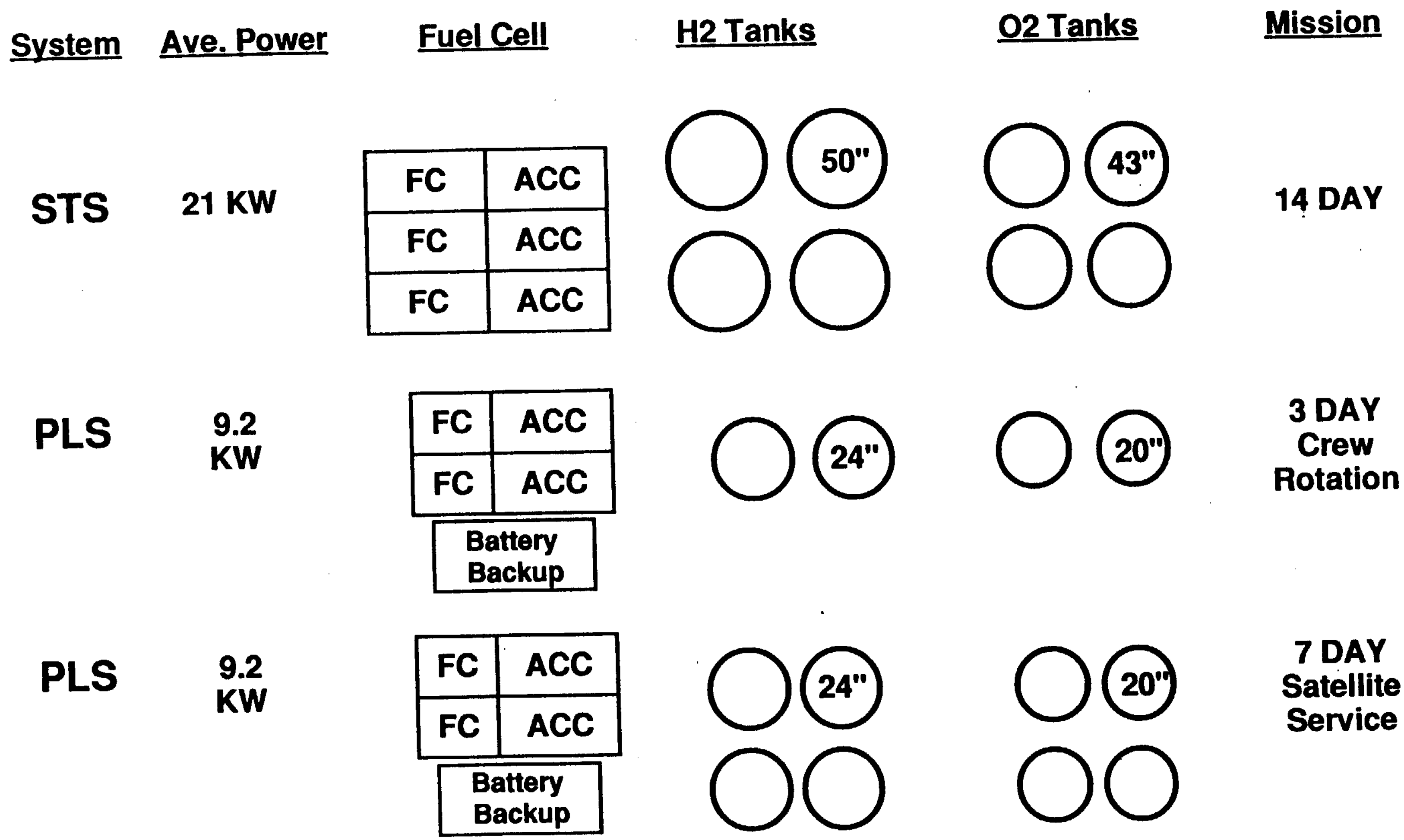


Figure 9.4-5 Comparison of STS and PLS EPS Hardware

transfer of heat into the structure. The lithium batteries provide improved performance as the internal battery temperature increases, therefore, some battery absorption of heat flow is desired. Passivation of the lithium electrode during extended non-use times is not a problem since low rate discharge of PLS will allow significant passivation buildup without compromising the voltage output. The new electrolyte of these batteries also offers improved prevention of electrode passivation.

Table 9.4-1 is an equipment list of the EPS hardware.

9.5 Vehicle Aerodynamics and Control

There are four main flight regimes that feature different control philosophies and hardware:

- Orbital Operations
- Proximity Operations
- Reentry
- Terminal Deceleration/Landing

For orbital operations, typical maneuvering involves small velocity changes and/or attitude changes and is accomplished by the use of reaction controls (discussed in Section 9.3). Similarly, proximity operations are performed near other spacecraft and are characterized as slow, precise attitude/velocity changes and require a lower thrust reaction control system.

For reentry, a combination of RCS and aerodynamics controls are used. All propulsive systems would be prohibitively heavy. Terminal landing phase control is dependent on the type of system selected, but must be designed to account for off nominal events and winds

Since the PLS aerodynamic characteristics influence both performance and crew safety, a range of designs was explored. These shapes were constrained by the contract to include only "wingless", lower L/D designs. Figure 9.5-1 shows the characteristic curves for a large heat shield, "shaped brake" configuration. Figure 9.5-2 depicts curves for a relatively high L/D design, the "wedge", at the upper end of the wingless configuration range. Finally, Figure 9.5-3 depicts the aerodynamic

Table 9.4-1 EPS Equipment List

WBS	Item	Qty	Hardware Wt. (Lb)		Prop. Wt (Lb)	Power W	Description	Heritage
1.1.9	Power Supply			1300		675		
	Fuel Cells	2	361				Reduced STS (14 kW Nom, 24 kW Peak	STS
	Batteries	6	432				Li-SOCl2 Expendable Batteries	New
	O2 Tankage (EPS & ECLSS)	2	90		372		Vacuum-jacketed Tank	New
	H2 Tankage	2	94		50		Vacuum-jacketed Tank	New
	Reactant Fill & Drain Plumbing	4	12					
	Reactant Relief, Vent Plumbing	4	64					
	Reactant Supply Plumbing	4	20					
	Reactant Supply Valves, Disc	4	12					
	Coolant Plumbing		15					
	Coolant Fluid		30					
	Power Supply Supt/Instl		170					
1.1.10	Power Dist Equip			169				
	Power Distr / Control Assemblies	2	99			33		
	10 vDC Power Supply	2	1			3.3		
	Lights - Interior / Exterior		35			150	Estimate	
	Power Distribution Supt/Instl		34					
1.1.10	Wiring			688				
	Power Distr. Wire Harnesses		400					
	Instrumentation Wiring		100					
	Electrical Connectors		50				Bulkhead Feedthrough Plates	
	Harness Supt/Instl		138					
	Power - Crew Module			**2157**	**422**	**862**		
	Wiring, Incl Ground Umbilicals			100				
	Connectors, Disconnect			50				
	Equipment Support/Instl			38				
1.6.10	**Power Distr. - OMS Module**			**188**				
	Power Distr. - LES			**40**				

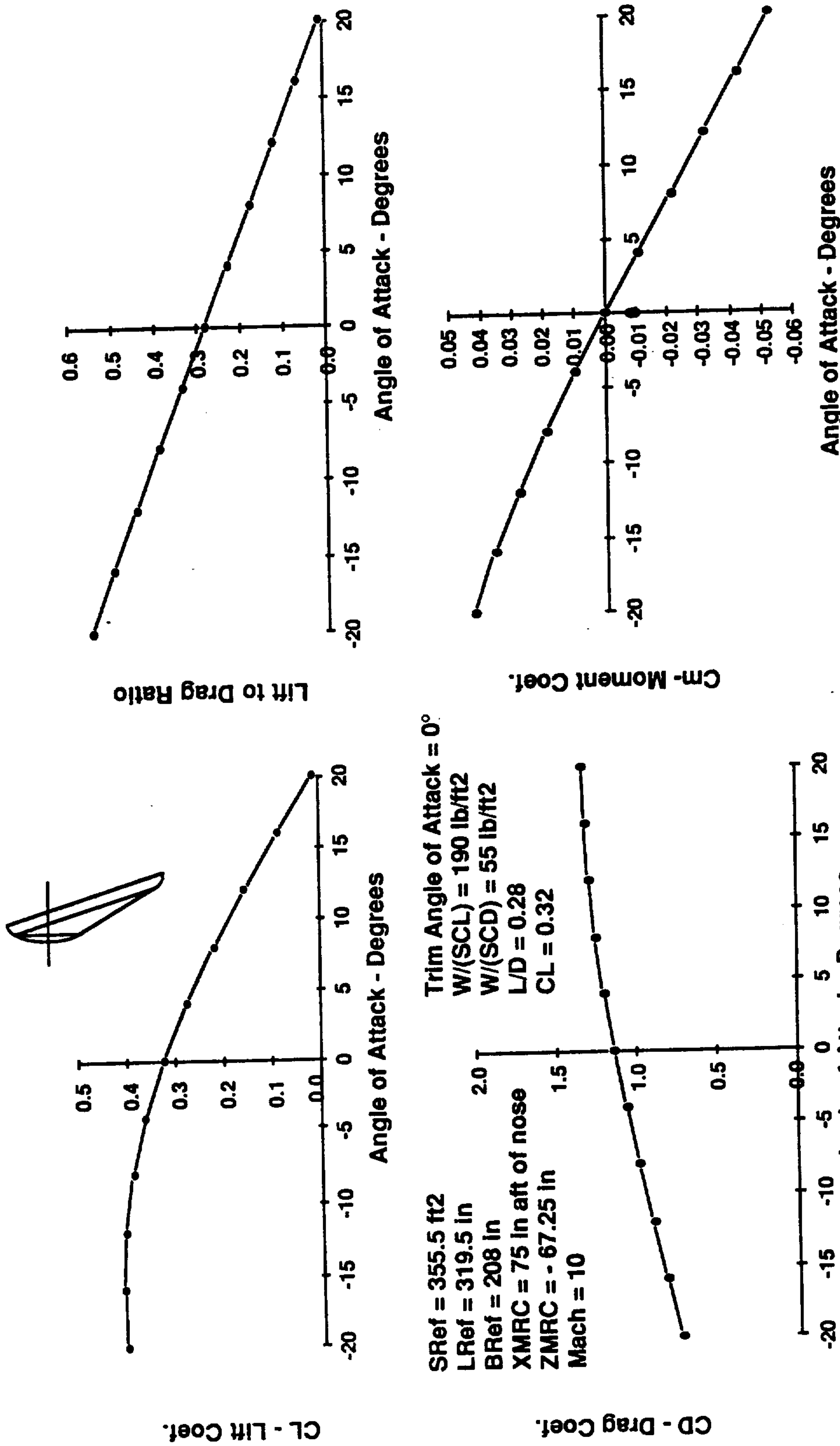


Figure 9.5-1 Aerodynamic Characteristics for "Shaped Brake" Configuration

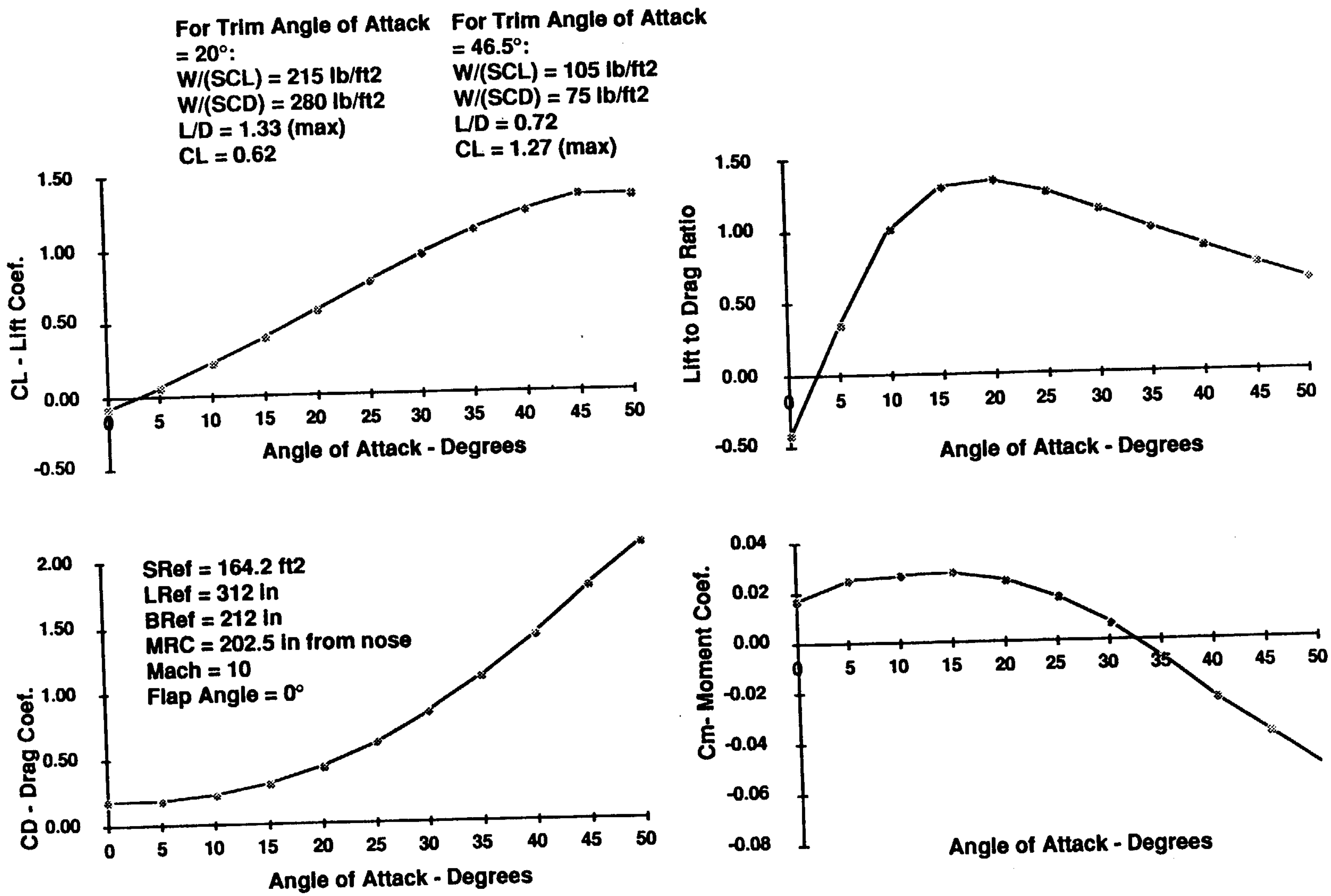


Figure 9.5-2 Aerodynamic Characteristics for "Wedge Configuration"

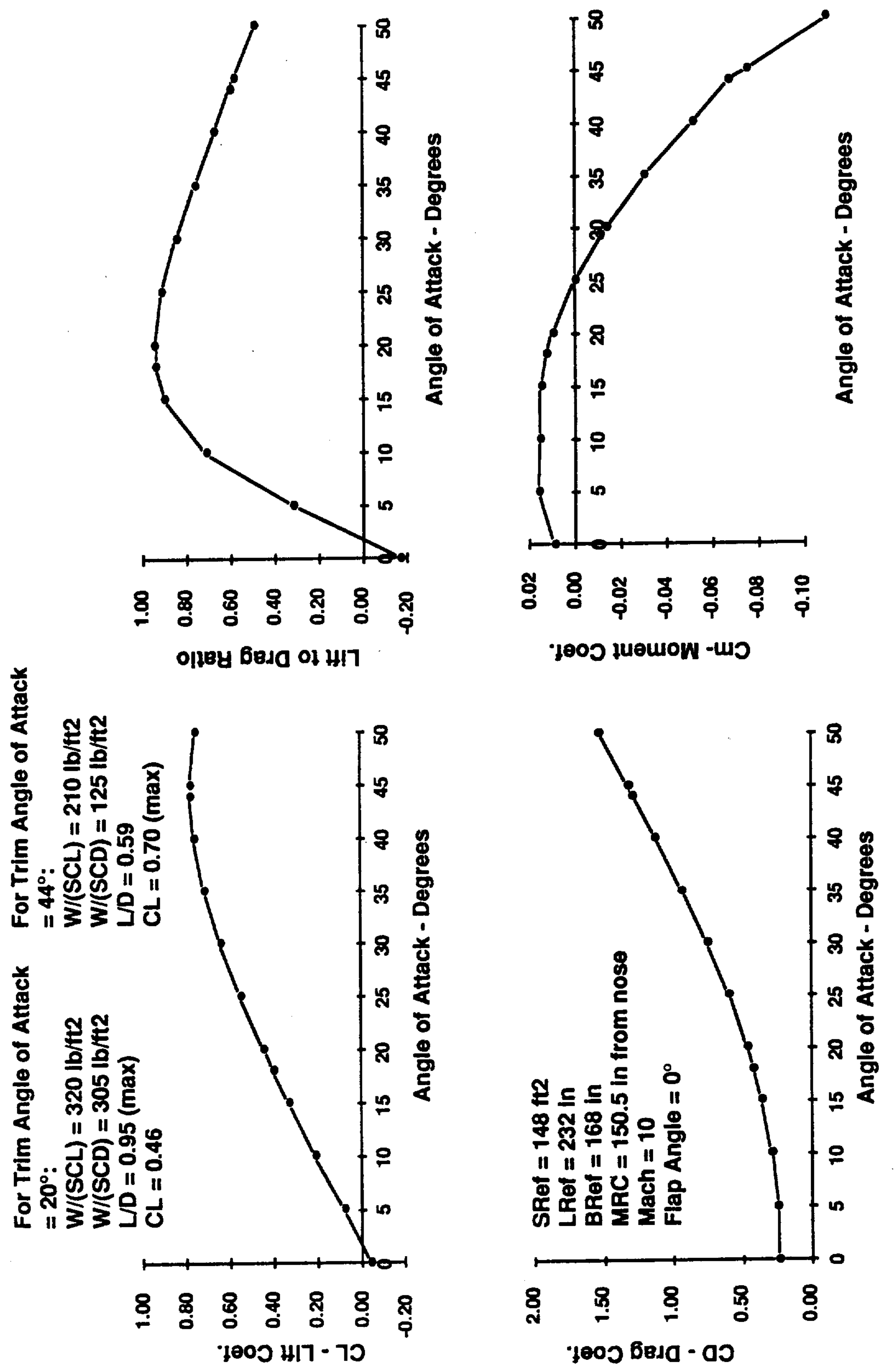


Figure 9.5-3 Aerodynamic Characteristics for Biconic Configuration

characteristics of the selected biconic configuration. The flat surface on the lower side of the vehicle is used in conjunction with a split body flap to improve stability and trim the vehicle. All data are shown for a 21,700 lbm vehicle at a velocity of Mach 10.

A body flap provides both pitch trim and control. The flap is split for roll control which allows bank modulation to minimize aerodynamic heating. Figure 9.5-4 illustrates the body flap pitch plane effectiveness. Dynamic pressure will determine the flight regime over which the flap is effective; a typical reentry would show a dynamic pressure loading like the one shown in Figure 9.5-5.

One drawback of the biconic shape (indeed a disadvantage of many low L/D shapes) is the absence of vertical surfaces which would improve the values of $Cn\beta$ and $Cl\beta$, aerodynamic coefficients related to roll/yaw stability. The vehicle tends to be poorly damped in yaw and will tend to oscillate. Depending on the level of acceptable motion, the RCS is used to control the vehicle. In a real, variable atmosphere, the amount of propellant required can be very significant. If further study of the biconic PLS is pursued, a trade between aerodynamic changes to improve the inherent stability and propulsive damping is necessary to determine an "optimum" propellant quantity. Such aerodynamic changes could include tabs extending vertically from the sides of the aft body, aerodynamic shaping of the body (such as flat spots on the side of the vehicle or incorporatiom of a "flatter" shape), or fixed or fold-out fins. Without the benefit of a full dynamic flight simulation in random atmospheres, the estimates for ΔV capability range from about 45 ft/sec to 220 ft/sec. A representative value of 120 ft/sec was selected as the RCS budget based on previous studies of a similar configuration. Typical control torques for an example reentry are shown as Figure 9.5-6, and a typical plot of RCS expenditure is shown as Figure 9.5-7.

For the terminal flight phase, a lifting parafoil device was selected (see Section 9.9). The control of the parafoil is effected by deflecting the trailing edge of one or both sides of the parafoil, much like an aircraft uses ailerons. Winches reel control lines in or out based on inputs from the guidance system. A typical control line displacement program is shown as Figure 9.5-8. An eight degree-of-freedom model was developed that was "tuned" with wind tunnel data and drop test data from the ARS program. A typical control response to a programmed command is shown in Figure 9.5-9. The correlation for a heading rate command for a drop test is shown in Figure 9.5-10. Even in variable winds, this control response provides the authority to land the PLS within a few hundred feet of the design impact point.

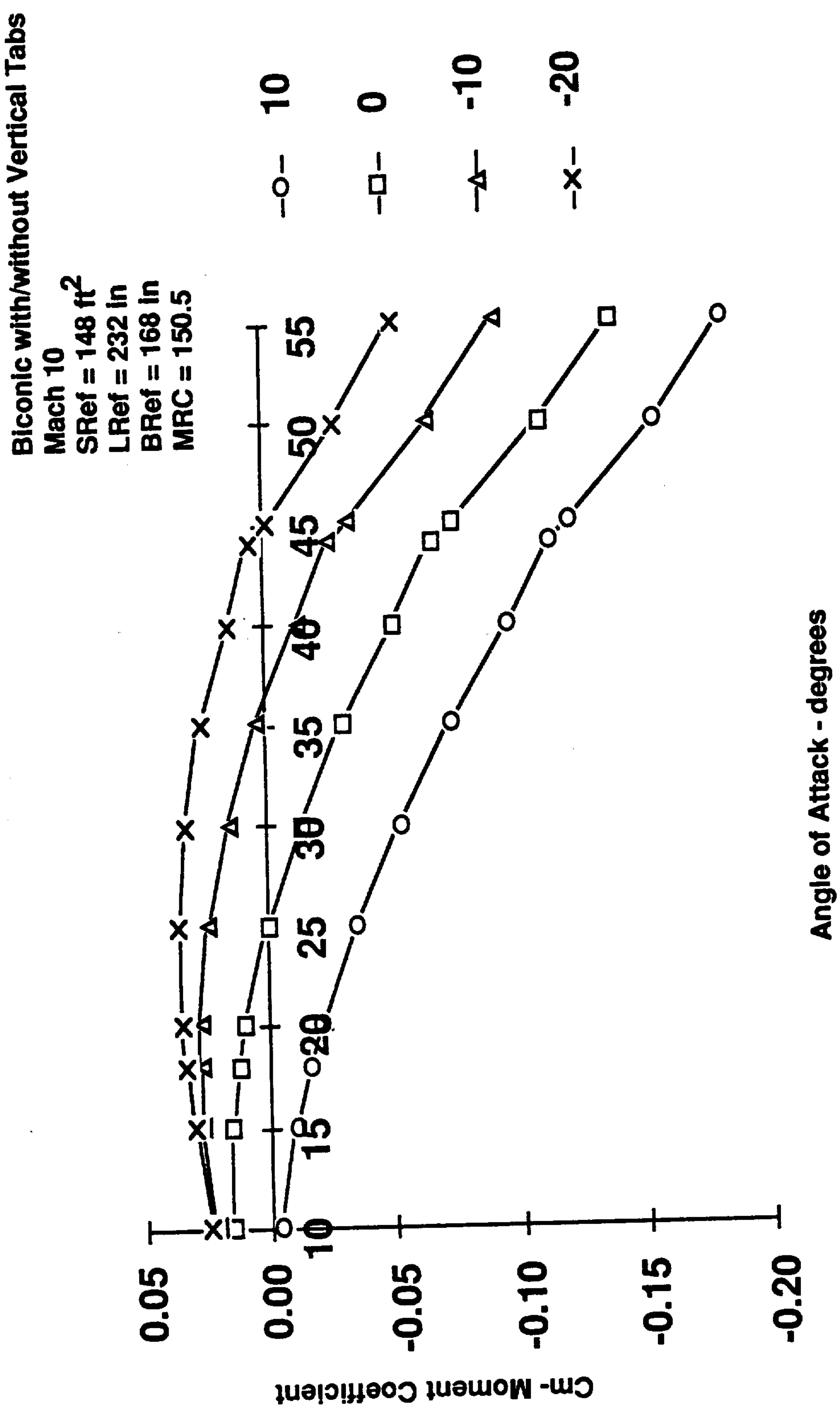


Figure 9.5-4 Flap Effectiveness for Biconic Configuration

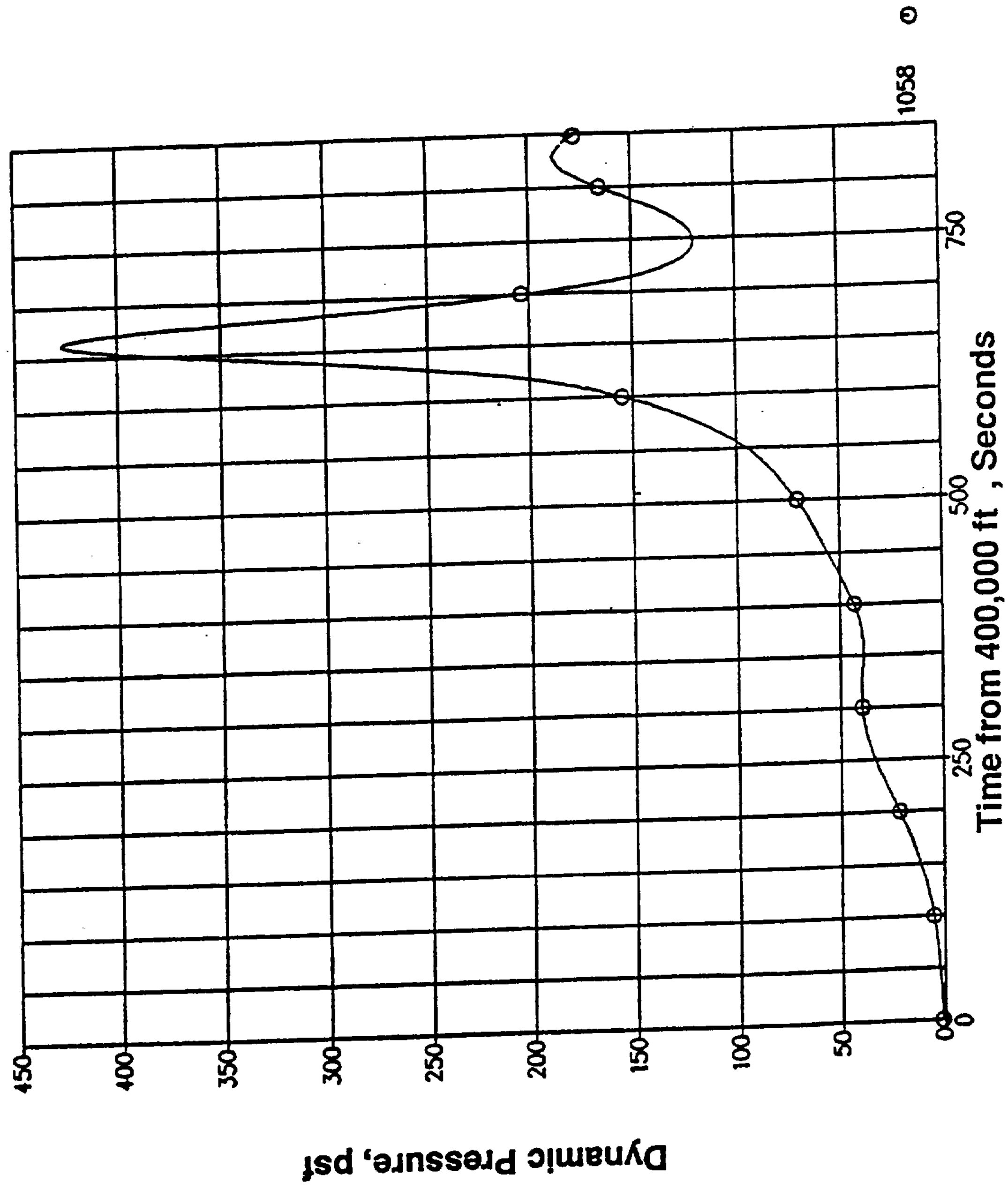


Figure 9.5-5 Typical Trajectory Dynamic Pressure Loading

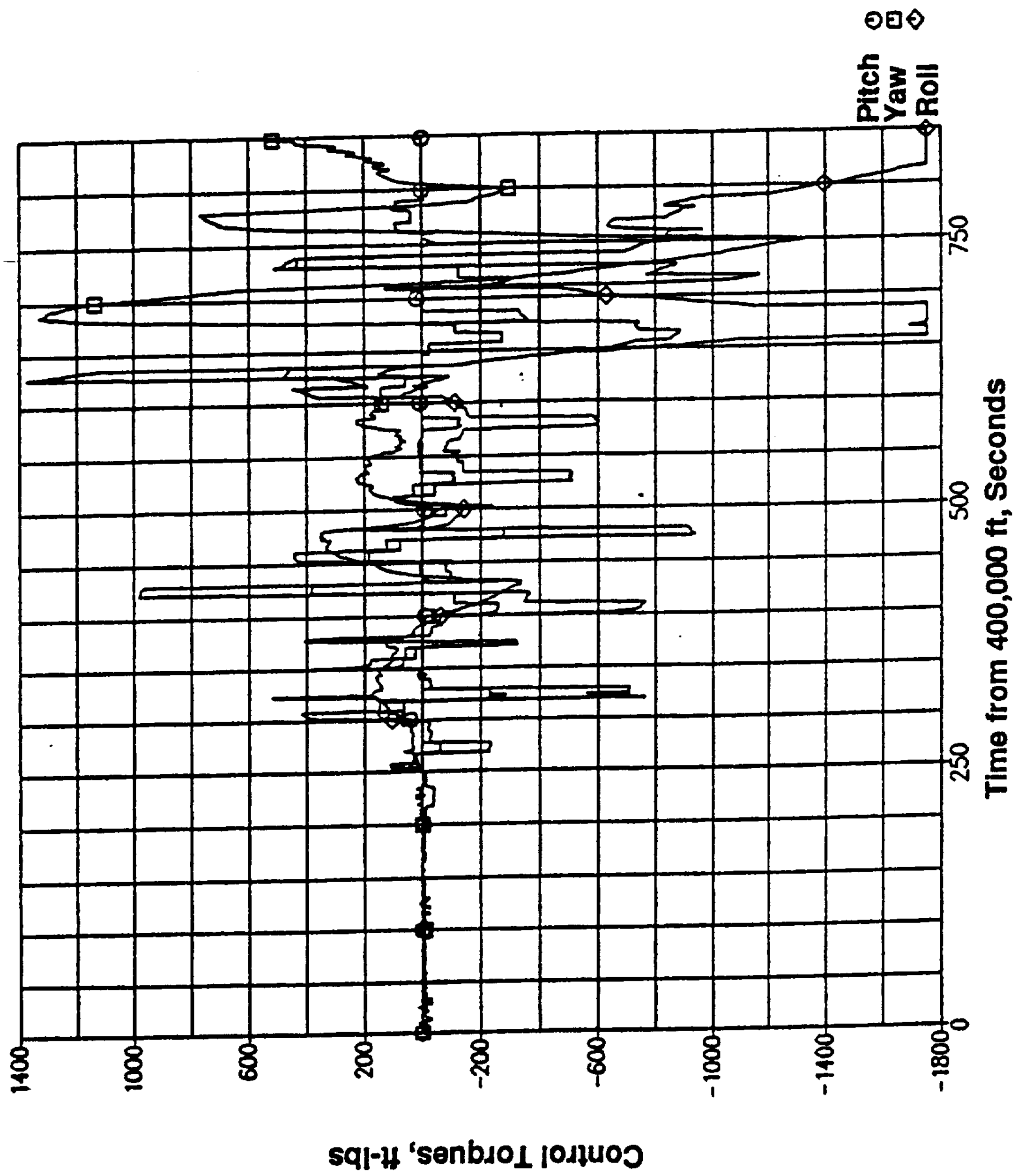


Figure 9.5-6 Typical Reentry Control Torques

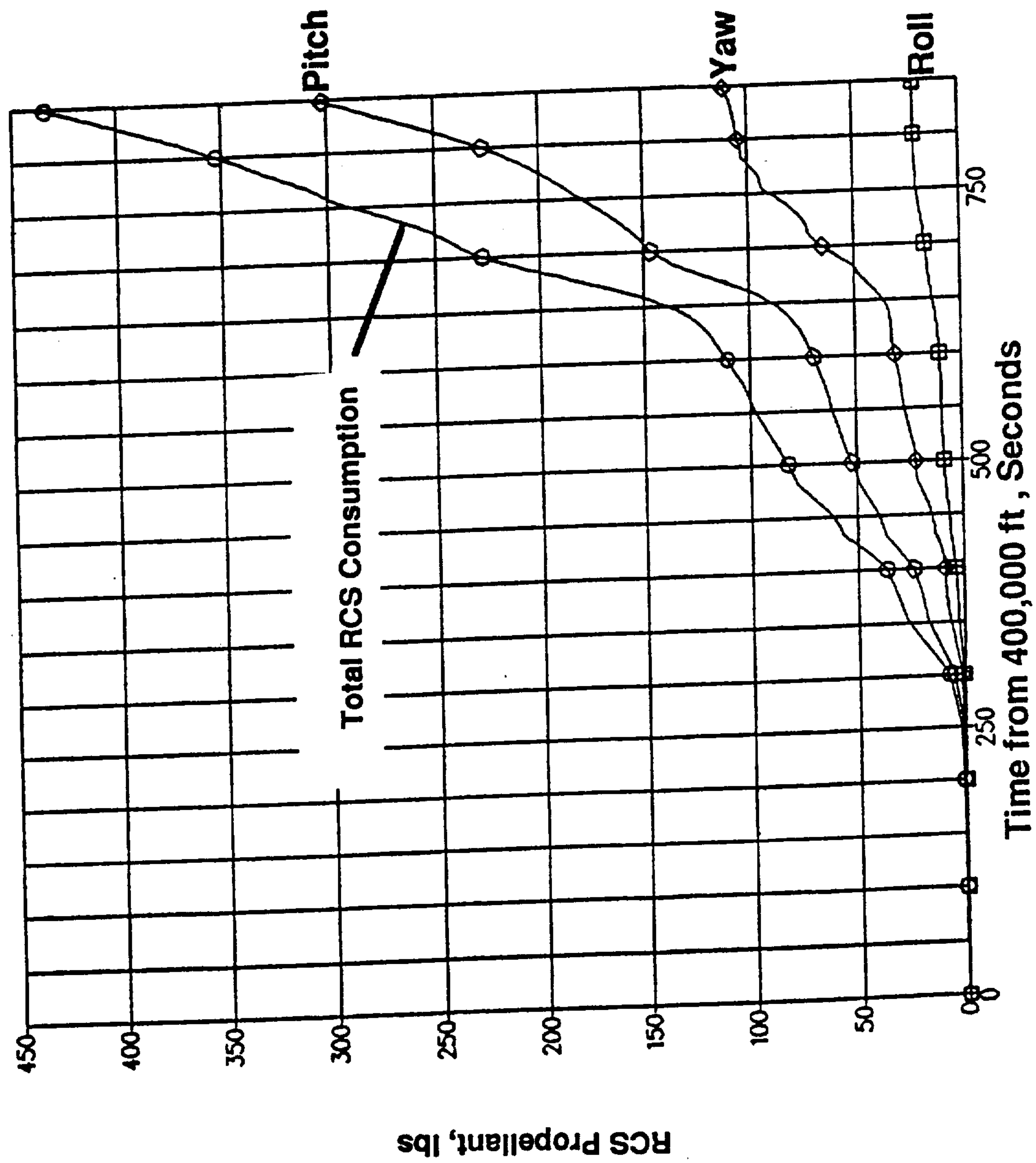


Figure 9.5-7 Typical Reentry RCS Expenditure

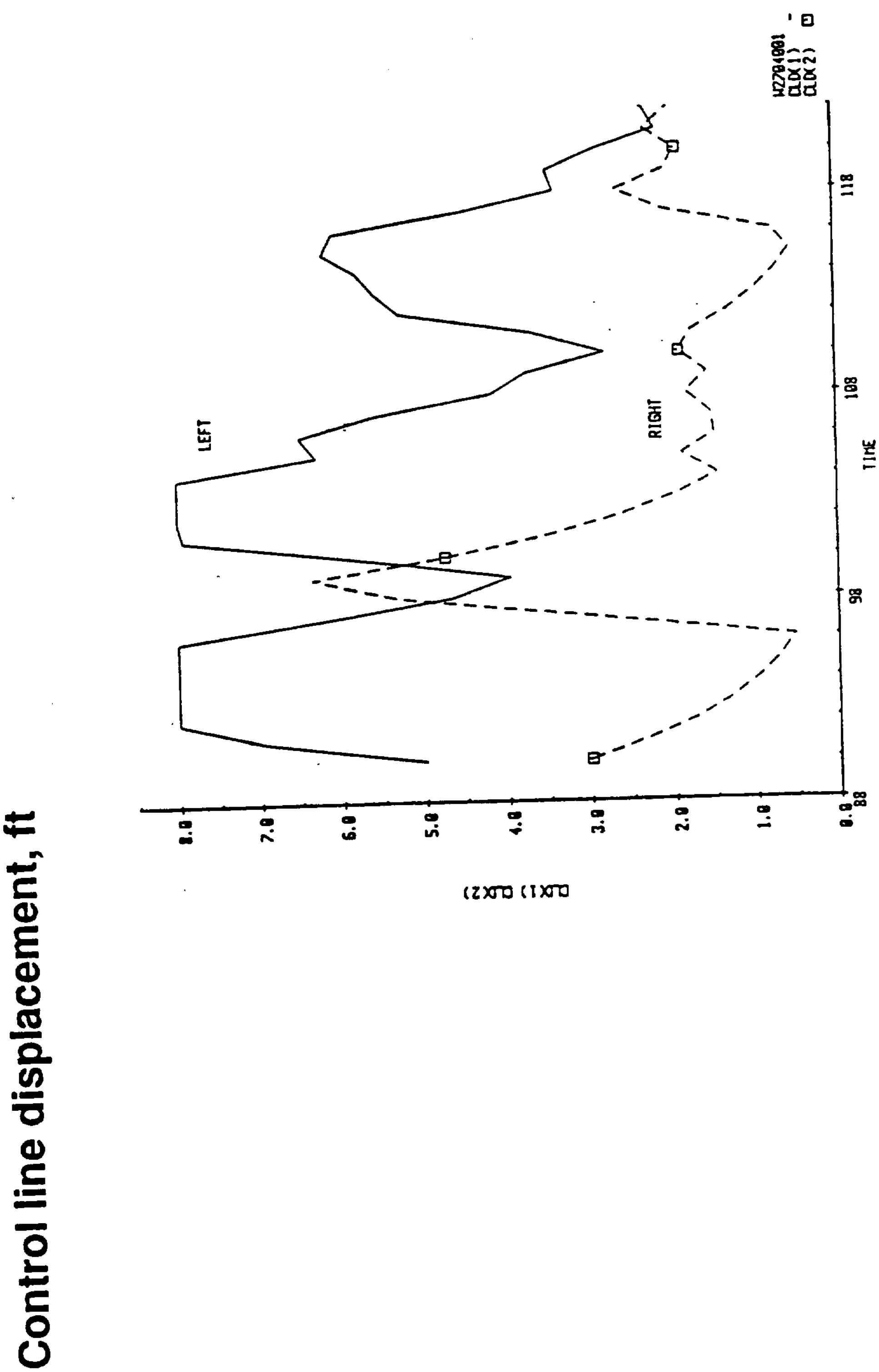


Figure 9.5-8 Typical Control Line Displacement

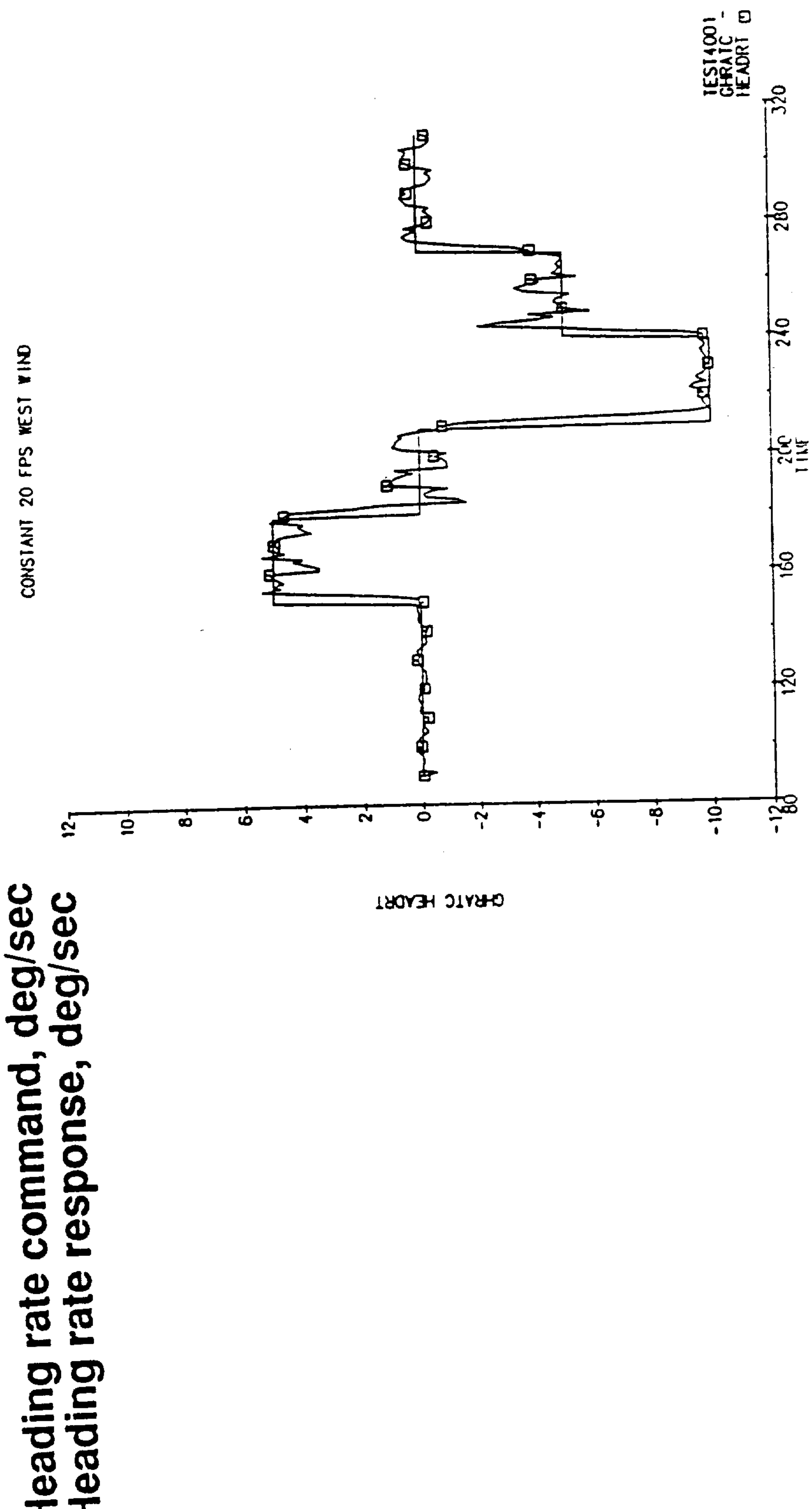


Figure 9.5-9 Parafoil Control Response to a Programmed Command

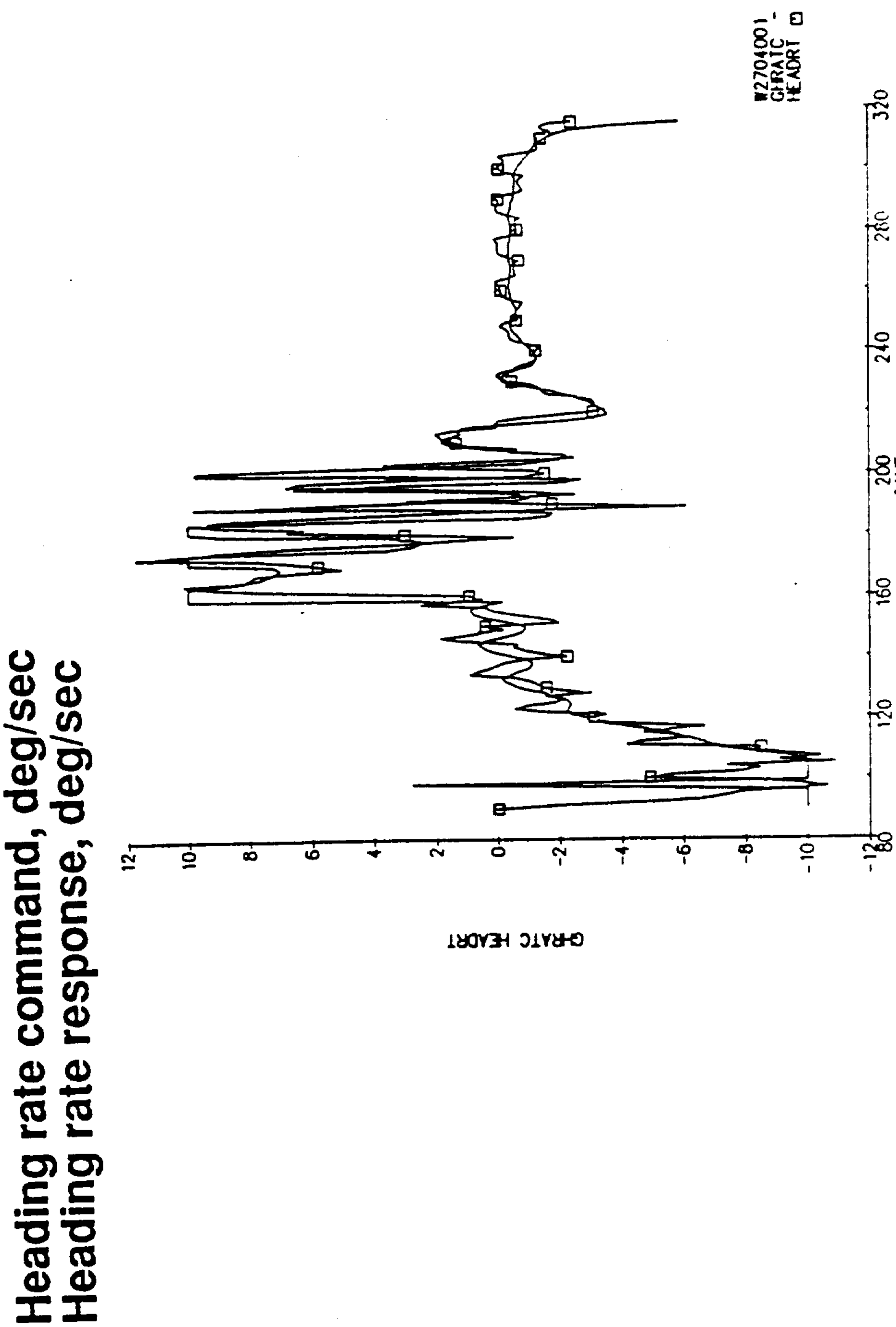


Figure 9.5-10 Heading Rate Command and "Response for Parafoil Drop Test"

9.6 Avionics

The JSC avionics requirements gave early emphasis to the issue of vehicle autonomy. Requirements such as "unmanned" operation and, manned operation but with no crew members, necessitate a design concept that needs a top down approach to avionics architecture, adaptive guidance, autonomous navigation, fault tolerance and vehicle health monitoring. In order to meet "efficient operations", the assumption was made that the vehicle would not be remotely piloted from the ground, but autonomously controlled by on-board resources with potential uplinked overrides.

9.6.1 Functions

The Functional Block Diagram (Figure 9.6.1-1) partitions the PLS system into eleven on-board functions. The functions support all phases of flight and ground operations required for a biconic-shaped vehicle without wheeled runway landing requirements.

Navigation measures position and velocity (six element state vector). During boost ascent, accelerometers measure the magnitude of velocity changes (ΔV) and gyros measure the direction of ΔV. Precise navigation fix prior to entry is required. Relative navigation using radar for rendezvous and docking to non-cooperative and cooperative targets will be used.

Guidance provides trajectory control autonomously by adapting to dispersions in thrust, center of gravity, modeling offsets, and unmodelled uncertainties. Manned spacecraft trajectory changes include rendezvous with SSF and other spacecraft, orbital operations for onboard payloads, and Earth reentry.

Flight control provides "attitude hold" pointing, rotating, spacecraft translation from one fixed attitude to another, and the holding of a fixed rotation rate for mission unique requirements. Propulsion control accepts attitude and velocity commands and provides required valve commands to RCS or OMS engines.

Controls and Displays provide crew/passenger interface by providing color displays with graphics, icons and audible cues. Crew controls are subject to an autonomy trade but range from simple menu selections to hand controllers for skilled, piloted "man-in-the-loop" operation. The main panel concept provides menu driven displays and programmable switches.

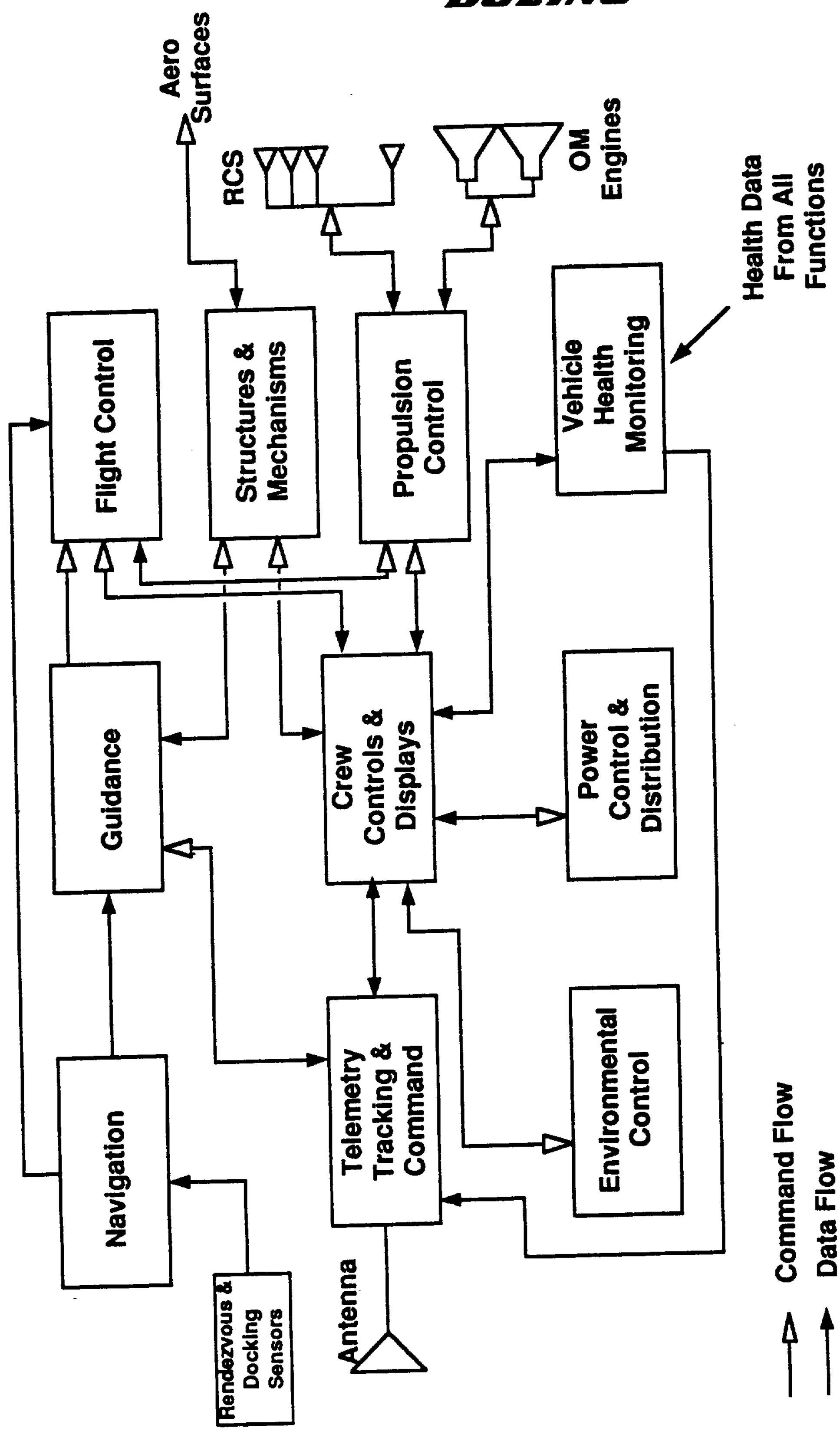


Figure 9.6.1-1 PLS Functional Block Diagram

The Telemetry, Tracking and Command (TT&C) function provides reception of uplinked switching commands (if necessary), downlink data and voice channels. A Ku-band system is used for 2-way digital, voice and TV communications with TDRSS (provided the antenna/platform is not being used for rendezvous navigation).

Vehicle Health Monitoring (VHM) is a rather new avionics function. VHM extends individual subsystem built-in-test, condition monitoring, status monitoring, and command state verification monitoring by considering the vehicle as a whole. Relations among disjointed subsystems and all vehicle stage elements are taken into account as an autonomous entity. As a fault propagates throughout the "system" and it's boundaries, the VHM function determines the state of health of the vehicle as whole. Information at this level is vital if the vehicle design is to be truly autonomous. Therefore, the VHM function must supply the vehicle state of health to a "system manager" which is the Mission Management function. The monitor and control of services in cabin and bays, electrical power, propellant, doors, chutes, and venting are shown in Figure 9.6.1-1 under other control functions.

9.6.2 System Control

A key ingredient of an avionics architecture is how the network (both electrical and electronic) will be controlled. The command and control of the functions is first determined. Figure 9.6.2-1 shows four levels of ever deepening control. The top level is where humans will always be able to gain control and access the system. In this scheme, on-board crew members may intervene by way of Mission Management. For unmanned missions (or no crew), uplink commands are sent to Mission Management via the Command part of TT&C. Normal autonomous control is via Mission Management. In fact, for any control input inflight or from ground processing, all lower tiered functions see the same path.

Level 2 functions see control only from Mission Management. This greatly reduces the system validation requirements and provides a clear design path for control flow. Each level 2 function is responsible for interfaces to level 3 transducers (sensors and effectors). This insures that the Vehicle Health Monitoring function does not become a "choke point" in gathering health data from each function. Because of the intervention and autonomy control, a so called "meta function" is formed by combining part of TT&C (uplink), all of Controls and Displays, Mission Management (control output) and VHM

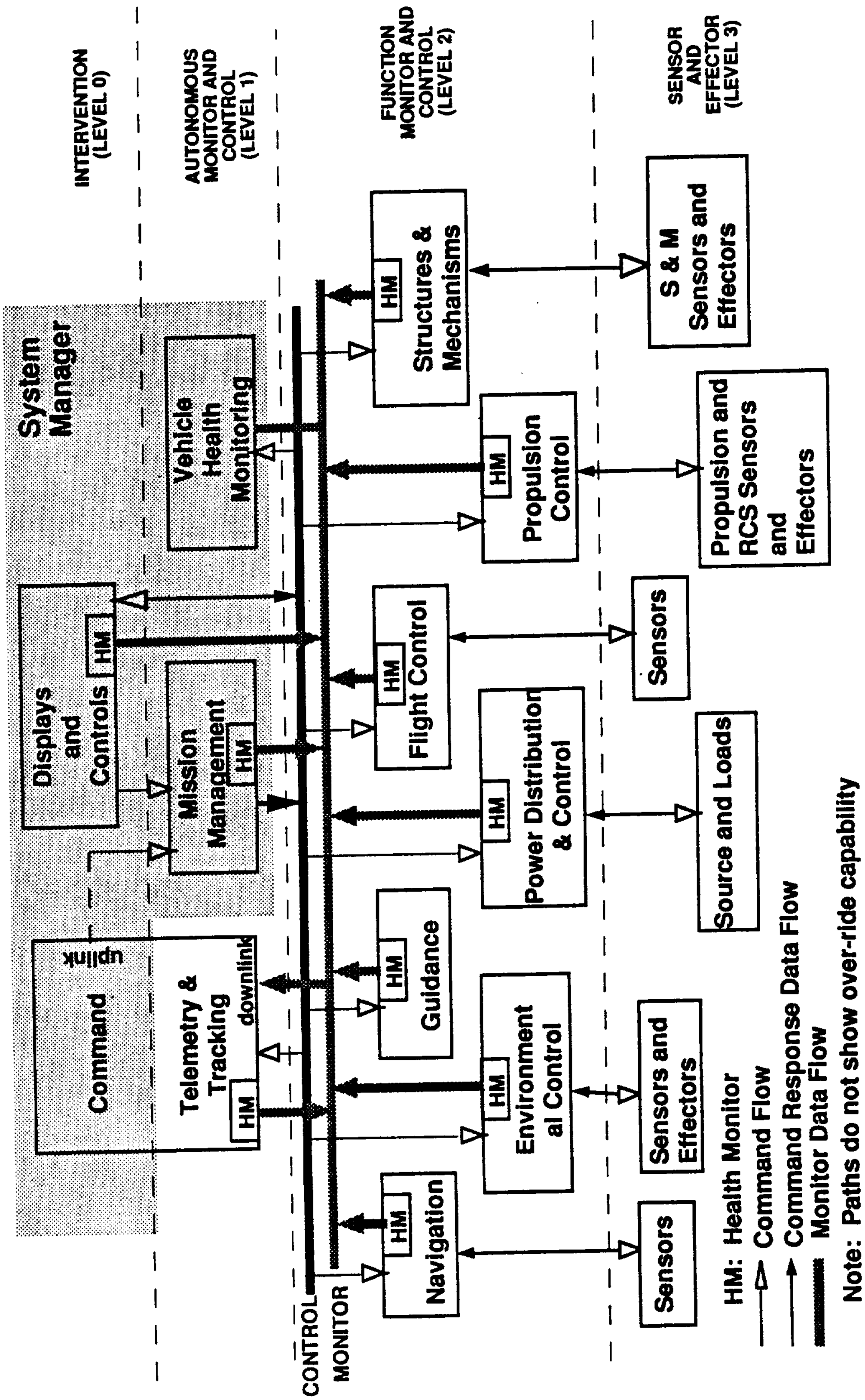


Figure 9.6.2-1 Avionics Command and Control Flow

(monitor input) into one higher level function. This forms the basis for ground assembly and test, ground checkout, prelaunch operations and all flight modes to recovery.

9.6.3 Selected Option

Figure 9.6.3-1 is a diagram depicting the PLS avionics architecture. Table 9.6.3-1 is a overall avionics equipment list covering the items discussed in the following paragraphs. There are many other trades (see Figure 9.6.3-2) that will need to be addressed at the preliminary design stage before the avionics concept definition would be complete.

9.6.3.1 Guidance and Control

Adaptive guidance and control optimizes the trajectory to minimize the error (CEP) and g-loading, and constrains heating rate during entry for given center-of-mass offsets and other non-nominal dispersions. Robust flight controls will provide attitude control and commands for vernier velocity changes in the presence of faulted jets as directed by guidance. Control authority will provide the required turning rates in space and orbital/entry maneuvers.

9.6.3.2 Navigation

In order to provide the vehicle state vector, an inertial grade Ring Laser Gyro (RLG) set of six components, each using a Hexad Inertial Measurement Unit (IMU) arrangement of skewed axes, is referenced. The skewed axes expands the fault tolerance coverage while minimizing the number of components. Growth to a less costly, space qualified, GPS-aided IMU is highly desirable. Horizon Scanners provide attitude reference for entry after departure from SSF. Note that the reliance on an SSF interface is reduced with the GPS position/velocity and horizon scanners providing vehicle attitude reference.

During orbital operations, a stowed Ku-band communications antenna will be deployed and will measure range, range-rate, and angles for relative navigation to a target. Non-cooperative targets will be tracked by skin tracking out to about 10 nmi. For a cooperative target (transponder), maximum distance to track is 200 nmi. This antenna will be stowed prior to deorbit phase.

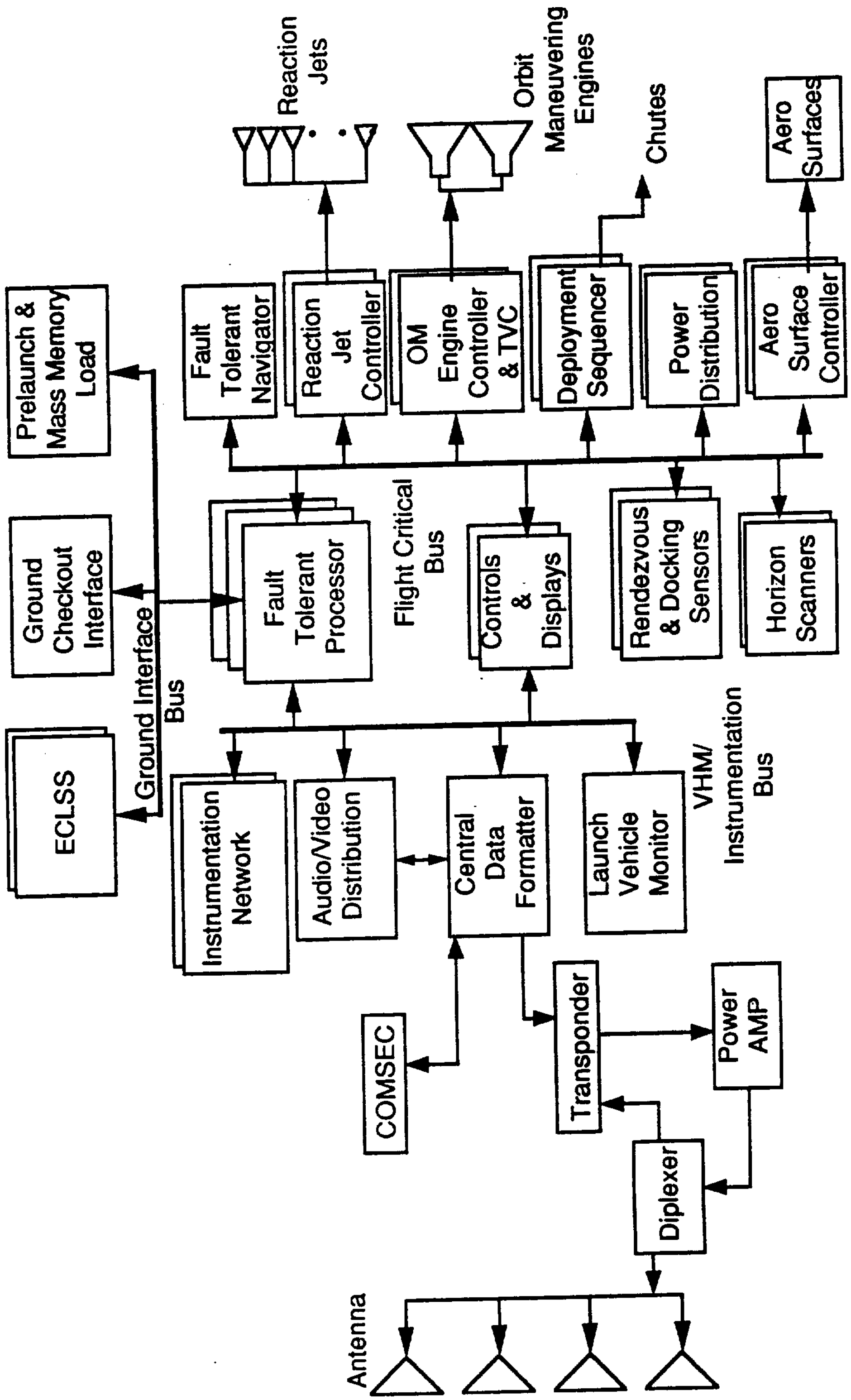


Figure 9.6.3-1 Selected PLS Avionics Architecture

Table 9.6.3-1 Avioincs Equipment List

Item	Qty	Wt (Lb)	Power Watts	ATR size **
Total Avionics		1637	3142	
Guidance, Navigation And Control		229		
Fault-tolerant Navigator	1	50	100	*
Gps Receiver	2	12	26	0.25
Gps Antennas	2	10	20	0.25
Horizon Scanner	2	12	16	0.25
Radar Altimeter	2	10		0.25
Body Flap Driver	1	45	270	0.75
Rcs/ Oms Valve Driver	2	90	144	
Rendevous And Dock		133		
Rendevous Radar	1	30	30	0.75
Radar Signal Processor	1	70	30	1.50
Antenna	1	8		0.25
Antenna Mast, Deployment Mechs	1	25		
Communications And Tracking		238		
Central Data Formatter	1	27	198	1.00
Transponder	1	16	28	0.50
Power Amp	1	18	200	0.38
Diplexer, Rf Switch	1	3		0.50
Audio / Video Distribution		40	100	0.75
Uhf Transceiver		20	200	0.38
Antennas	3	24		0.25
Search and Rescue Radio	1	40	100	
Signal Cabling		50		
Health Management		75		
Mass Memory	3	75	300	0.38
Controls And Displays		185		
Reconfigurable Displays	5	50	175	0.25
Panel Control Units	2		20	
Electronic Interfaces	3	75	225	0.50
Reconfig. Push-button Panel	3	30	45	0.25
Hand Controllers	2	30		
Instrumentation		83		
Sensor Interface Unit (Siu)	60	30	34	0.25
Network Interface Unit (Niu)	2	3	30	0.25
Sensors, Instrumentation	700	50		
Data Handling		463		
Fault Tolerant Processor	3	99	531	1.50
Mass Memory	3	75	300	0.38
Data Bus		30		
Mdm	7	259		1.00
Structures/Mechs Controls		82		
Chute, Landing Gear Controller	1	61		1.00
Laser Firing Unit	2	20	20	0.25
Laser Initiators	5	1		
Avionics Supt/Instl		149		

** ATR SIZES	
0.25 ATR size:	2.29 x 7.64 x 12.5
0.38 ATR size:	3.56 x 7.64 x 12.5
0.50 ATR size:	4.88 x 7.64 x 12.5
0.75 ATR size:	7.50 x 7.64 x 12.5
1.00 ATR size:	10.09 x 7.64 x 12.5
1.50 ATR size:	15.29 x 7.64 x 12.5
*	12.0 x 8.0 x 19.5

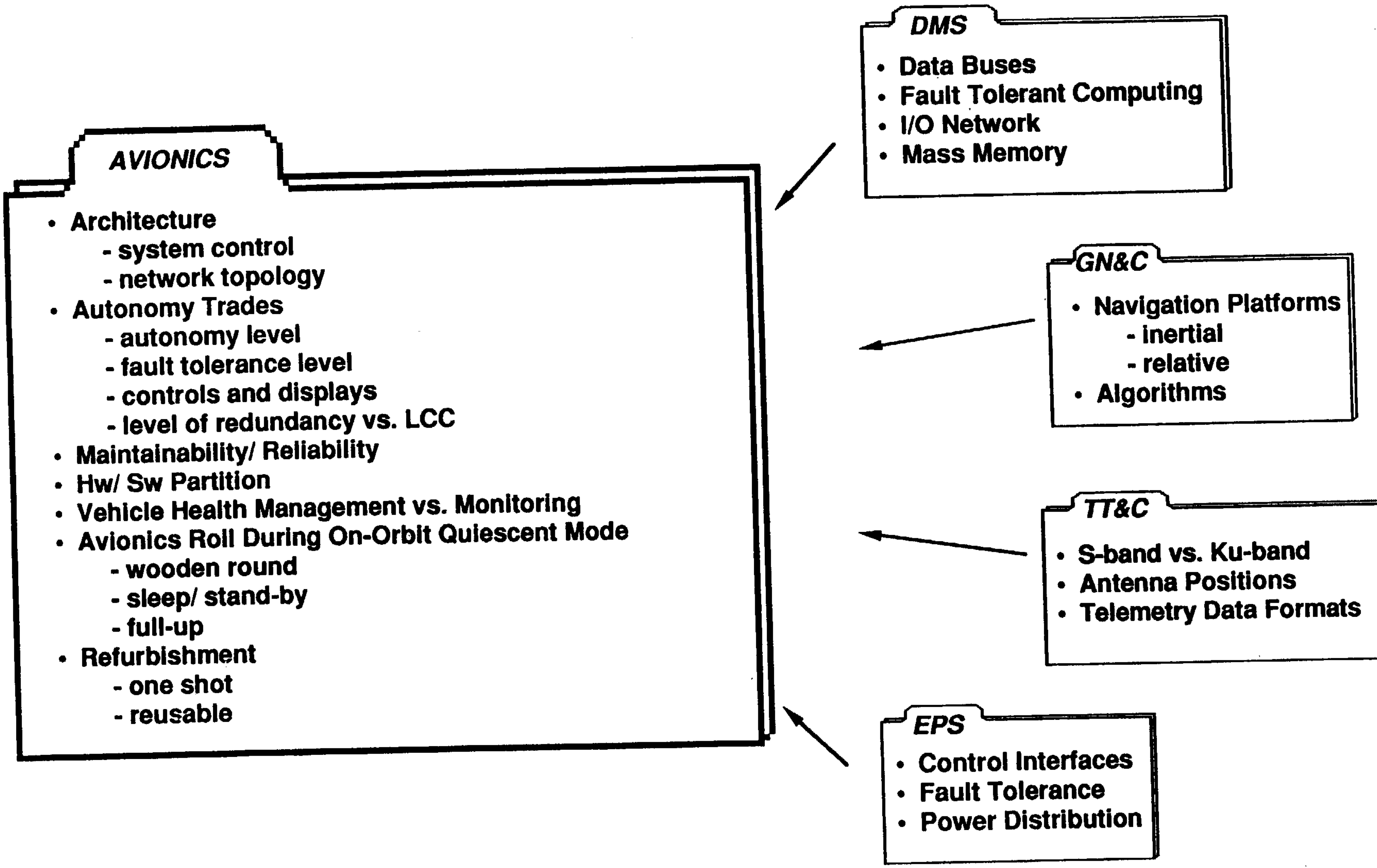


Figure 9.6.3-2 Avioincs Justification Trades for Future Study

9.6.3.3 Data Management

The PLS avionics architecture topology is a federated set of processors. The fault tolerant processor site interfaces to three photonic networks. Functional partitioning of flight critical signals from essential and non-essential signals reduces validation costs and recertification when components are changed or new ones added. This design is more distributed than the STS Shuttle. Notice the absence of MDM's at the interfaces between computers and subsystem sensors and effectors (autonomy level 3). This places requirements on subsystem components to be able to connect directly to the data buses.

The three bus networks are contained in the same media. Separation of signals is by wavelength division multiplexing. The advantage is found in a large reduction in physical connectors which increases reliability (physical connectors are well known to be the single largest contributor to unreliability). Appropriate redundancy, coupled with physical separation of redundant channels, gives rise to a "zero-down-time" network.

Bus network types that are current networks or are about to be available for space application include: Shuttle 1Mbps data bus (pre MIL-STD-1553); US/NATO combat aircraft MIL-STD-1553B; MIL-STD-1773 (the fiber optic equivalent of 1553) with transmissive or reflective nodes; 10 Mbps IEEE 802.4 a bus utilizing token passing as the access method of an IEEE standard 802 local area network (a potential network on SSF); 50 Mbps HSDB Linear (SAE AS4074.1) and HSDB Ring (SAE AS4074.2) and; 100 Mbps FDDI (SSF). The three data bus media that form the physical layer for the above standards are twisted wire pair, coax, and optic fiber.

The trend in modern avionics is toward common modules. This reduces implementation costs, increases maintainability (high level of BIT and standard interfaces) and allows resource utilization. Some common types include: Space Station Freedom DMS Standard Data Processor and a low power processor both based on the Intel 80386 instruction set; Network Interface Units; Bus Interface Adaptor and; MultiBus II backplane . The U.S. Congress has mandated use by ATF (USAF), A-12 (Navy) and LH (USA) of common modules. DoD's Joint Integrated Avionics Working Group (JIAWG) uses MIL-STD-1750A processor, SAE HSDB, MIL-STD-1553, bulk memory modules, programmable input/output modules, and power supply

modules. While JIAWG provide a low cost solution, they are not "S-equal" parts and are somewhat heavy (about 1.25 lb per module).

9.6.3.4 Communications and Tracking

S-Band is the primary low rate interface for downlink telemetry and voice. The Ku-Band high data rate, 2-way link will be via TDRSS. The antenna is aimed at the TDRS during communications which precludes its use as a rendezvous sensor. High resolution, closed circuit CCTV, VHM data dumps are possible with bandwidth access of 180 to 300 Mbps. Image compression chip technology, if available in the PLS timeframe, may allow NTSC (color) quality communication over S-Band.

9.6.3.5 Controls and Displays

The selection of a main control and display panel was developed in consultation with a variety of astronauts and crew systems experts. Graphically, Figure 9.6.3.5-1 shows a layout featuring three Liquid Crystal Displays (LCD). This technology features low power requirements and is the state-of-the-art in current generation military aircraft and commercial airliners. The LCDs can display graphical or numerical output and are driven by separate controllers for redundancy. The displays and pushbuttons are reconfigurable and would assist in reducing information overload by presenting only the data applicable to the current flight phase.

9.6.4 Autonomy

Autonomy means on-board decision making electronics and software with human intervention capability. Areas include: (1) ground interaction reduction, (2) spacecraft integrity maintenance, (3) autonomous features transparency and (4) on-board resource management. The PLS study has focused mainly on item (3). Before discussing the trade options, some definitions are in order. The following (from Reference 18) should serve to clarify some terms:

> Autonomy- Autonomy is that attribute of a system that allows it to operate without external control and to perform a specified mission at an established performance level for a specified period of time. (Autonomous Duration will be a specified interval defined for each mission phase and for each reference mission.)

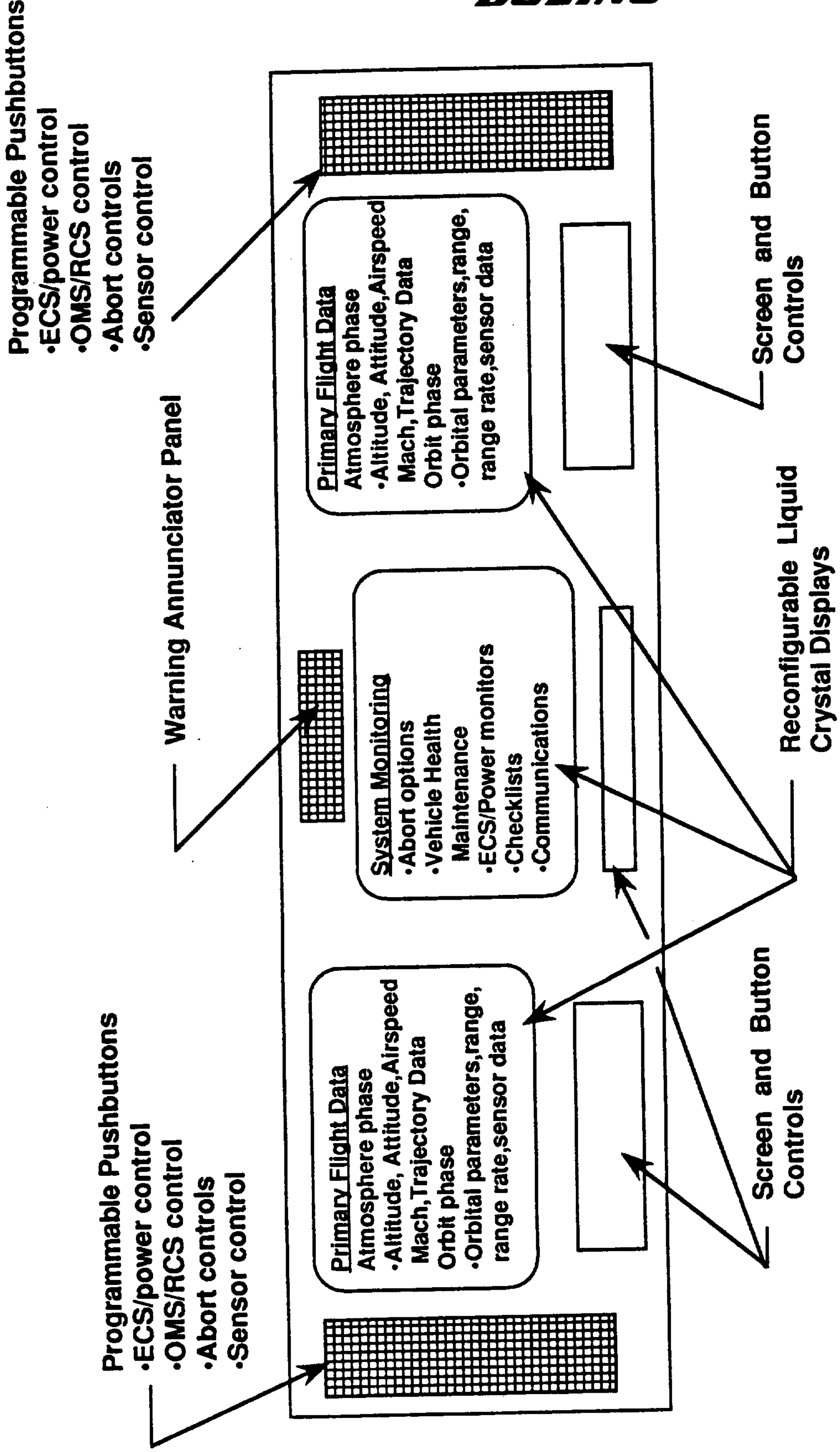


Figure 9.6.3.5-1 Main Display Panel Concept

Autonomous Process- A process that incorporates control structure logic to assess the appropriateness of its automatic function from internal and/or external sensory inputs and modify the automatic processes as needed.

Automatic Process- A process that is controlled in repetitive fashion until disturbed or modified by external inputs.

The design methodology (Figure 9.6.4-1) was set at the beginning of the study since the results imbed directly into the overall philosophy of architecture development. Autonomy requirements must be limited to the extent of the period of performance, in this case by mission mode (or phase) and event time during the mode. Once the method is set, the process is straight forward. Given the vehicle configuration, modes of flight, and ground interactions, control functional requirements are determined for the hierarchical structure. The tendency is to consider the vehicle as a flight segment only, however, system requirements for the ground segment as well as the flight segment must be included in the design process. The development of documented baseline requirements is iterative. As system requirements change, the autonomy requirements must be updated accordingly during each iteration.

The degree of crew/passenger interaction with vehicle control was divided into six options. These options range from least autonomous with a crew of 2, to no crew and fully autonomous in all phases (see Table 9.6.4-1). The avionics impact in terms of sensor requirements, fault tolerance, electrical power and cooling, and crew systems were traded. The top row represents POD weights at the time the study was started. As autonomy level increases, the reliance on on-board electronics increases. With at least one skilled crew member, the requirement for two failure tolerance against catastrophic hazards would apply (see Reference 19). If there are only passengers and no crew, fail operational/fail operational/fail safe capability was judged to be required.

As the level of autonomy increases, the avionics weight (1) increases for TT&C because the ground and mission control will want more downlink telemetry and uplink command capability, (2) decreases for Controls and Displays since there are fewer interactive operations, (3) increases for the DMS because the algorithms are more complex, (4) increases for navigation since sensor redundancy and type increase,

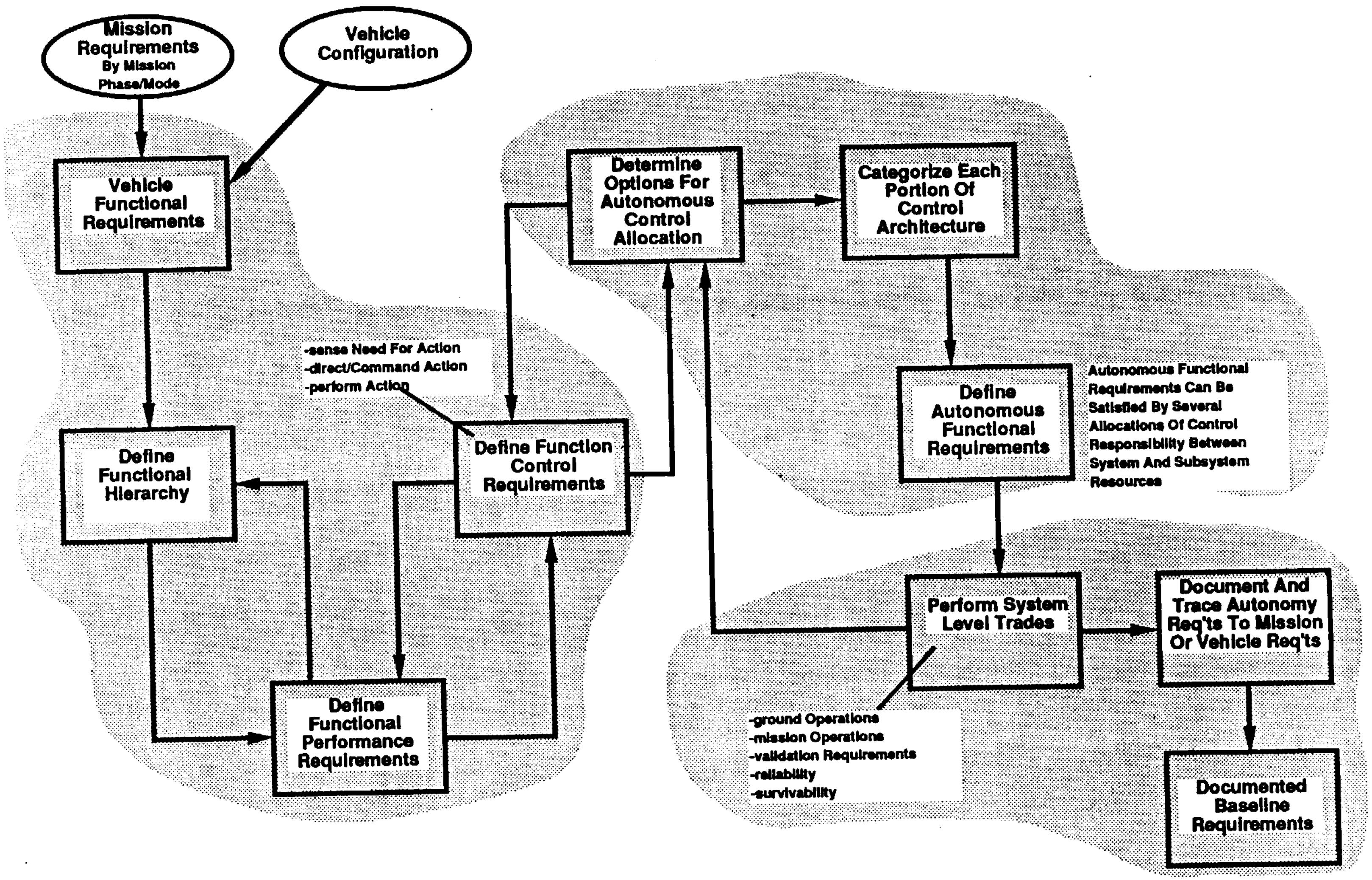


Figure 9.6.4-1 Design Methodology for Autonomous Systems

Table 9.6.4-1 PLS Autonomy Options

Personnel = Passengers + Crew

Autonomy option 1: (POD)	• Pilot & Co-pilot • Full training for crew control • Lowest level of autonomy
Autonomy option 2:	• Pilot only (autonomous avionics replaces Co-pilot) • Reduction in crew training and training facilities
Autonomy option 3A:	• No crew • Autonomous rendezvous navigation to docking • Low authority passenger in-the-loop for minimal pilot/ co-pilot workload
Autonomy option 3B:	• No crew • Low authority passenger in-the-loop except for dock/undock and collision avoidance maneuvers (autonomous avionics replaces <u>MOST</u> pilot/co-pilot workload)
Autonomy option 4A:	• No crew • Full authority autonomous vehicle control for all mission phases • No passenger action required • No training • Highest level of autonomy
Autonomy option 4B:	• No crew • Full authority autonomous vehicle control for all mission phases except SSF proximity operations • Lowest level of passenger action required • Lowest level of training • High level of autonomy

especially if rendezvous (Options 3A and 4A) is autonomous, (5) increases for Vehicle Health Monitoring since environmental and operational sensors will have to replace crew observations and crosslinking readings, (6) increases electrical power and cooling requirements due to higher electrical power dissipation and heat, and, (7) ECLSS and personnel provisions decrease as personnel (pilots) are eliminated. Table 9.6.4-2 is a weight comparison of the six autonomy options. For autonomous rendezvous and docking, redundant sensors and sensor processors were assumed to be required even for such conservative docking rules as the "0.1% rule" where commanded approach speed is 0.1% of sensed distance. See Figure 9.6.4-2.

9.6.5 Flight Software

The PLS flight software high level language is baselined as Ada. However, the PLS mission profile is not unlike STS Shuttle orbital operations and entry. Shuttle already has qualified HAL/S generated flight code that might be applicable to PLS. Studies at Charles Stark Draper Labs and IBM Houston have looked at the question of conversion of HAL/S to Ada. This work should be monitored by PLS for use. Software lines of code is estimated in Section 14 of this document.

9.7 Environmental Control and Life Support System

The environmental control subsystem (ECLSS) consists primarily of an atmosphere revitalization system and hardware for equipment cooling and heat rejection. Several key trades were performed to determine the best solution for a PLS ECLSS and are discussed in the following sections.

A hardware schematic for the ECLSS is shown in Figure 9.7-1. Table 9.7-1 contains a listing of equipment items represented in the schematic. Some items are listed that could not be shown on the schematic because of space limitations.

These items include the individual controls for the cabin pressurization and composition control subsystem, LiOH cannister storage, the ambient temperature contaminant removal cartridge, equipment cold plates, coolant tankage for the flash evaporator, and the electronics, valves, and actuators necessary to make all of this equipment functional. Quantities, dry hardware weight, consumables weight, and hardware volume and power estimates are listed for each itemized piece of equipment. These estimates do include the associated valves, actuators, motors, electronics, etc.

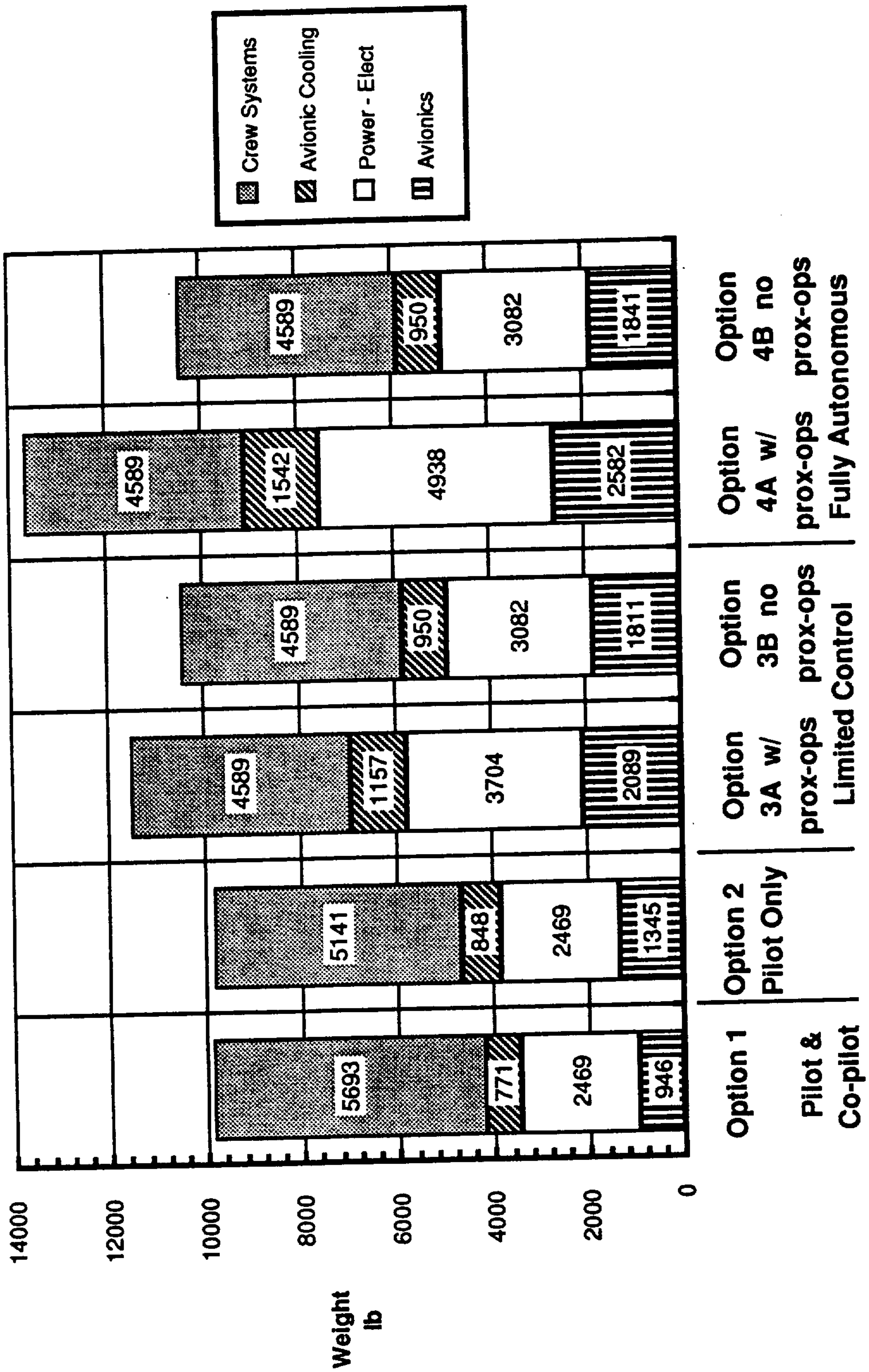


Figure 9.6.4-2 PLS Autonomy Level Weight Impact

Table 9.6.4-2 Weight Comparison of Autonomy Options (Page 1 of 2)

GROUP WEIGHT COMPARISON AUTONOMY TRADE	PERSONNEL LAUNCH SYSTEM FLATTENED BICONIC SHAPE (10-PERSONNEL SIZE)											
	Option 1 (POD)		Option 2		Option 3A		Option 3B		Option 4A		Option 4B	
ITEM	Qty	VALUE	Qty	VALUE	Qty	VALUE	Qty	VALUE	Qty	VALUE	Qty	VALUE
AVIONICS		946		1345		2069		1811		2582		1841
DISPLAYS AND CONTROLS		229		115		46		81		0		81
GUIDANCE, NAVIGATION AND CONTROL		167		334		501		501		501		501
DATA HANDLING		149		298		447		447		447		447
COMMUNICATIONS AND TRACKING		148		178		207		207		237		237
RENDEVOUS AND DOCK		170		255		680		400		1190		400
INSTRUMENTATION / HEALTH MONITORING		83		166		208		175		208		175
POWER - ELECTRICAL		2469		2469		3704		3082		4938		3082
IN-FLIGHT LOSSES		466		466		699		583		932		583
FUEL CELL USABLE O2		414		414		621		518		828		518
FUEL CELL USABLE H2		52		52		78		65		104		65
POWER SUPPLY		727		727		1091		907		1454		907
FUEL CELLS	3	225	3	225	3	338	3	281	3	450	3	281
O2 TANKAGE (EPS & ECLSS)	1	215	1	215	1	323	1	268	2	430	1	268
H2 TANKAGE	1	227	1	227	1	341	1	283	2	454	1	283
REACTANT PLUMBING		50		50		75		62		100		62
COOLANT PLUMBING		10		10		15		12		20		12
POWER DIST EQUIP		315		315		473		393		630		393
WIRING		700		700		1050		874		1400		874
ELECTRICAL POWER SUPT/INSTL		281		261		392		326		522		326
ENVIRONMENTAL CONTROL		771		848		1157		950		1542		950
HEAT TRANSFER WATER LOOP		351		386		527		432		702		432
EQUIPMENT COLD PLATES		120		132		180		148		240		148
AVIONICS COOLING ASSY		28		31		42		34		56		34
HEAT EXCHANGER - WATER, LCVG	3	30	3	33	3	45	3	37	3	60	3	37
PRIMARY, SECONDARY WATER PUMPS		78		86		117		96		156		96
PLUMBING		59		65		89		73		118		73
COOLANT IN LOOP - WATER		36		40		54		44		72		44
HEAT TRANSFER FREON LOOP		222		244		333		274		444		274
HEAT EXCHANGERS	3	50	3	55	3	75	3	62	3	100	3	62
FLOW PROPORTIONING MODULE	2	9	2	10	2	14	2	11	2	18	2	11
PUMPS, ACCUMULATORS, PLUMBING	2	102	2	112	2	153	2	126	2	204	2	126
COOLANT IN LOOP - FREON		61		67		92		75		122		75
HEAT REJECTION		198		218		297		244		396		244
AMMONIA BOILER ASSEMBLY		45		50		68		55		90		55
FLASH EVAPORATOR - WATER		73		80		110		90		146		90
TOPPING DUCT ASSEMBLY		56		62		84		69		112		69
HIGH LOAD DUCT ASSEMBLY		24		26		36		30		48		30

Table 9.6.4-2 Weight Comparison of Autonomy Options (Page 2 of 2)

GROUP WEIGHT COMPARISON AUTONOMY TRADE	PERSONNEL LAUNCH SYSTEM FLATTENED BICONIC SHAPE (10-PERSONNEL SIZE)											
	Option 1 (POD)		Option 2		Option 3A		Option 3B		Option 4A		Option 4B	
ITEM	Qty	VALUE	Qty	VALUE	Qty	VALUE	Qty	VALUE	Qty	VALUE	Qty	VALUE
CREW SYSTEMS		5693		5141		4589		4589		4589		4589
CABIN AND PERSONNEL SYSTEM		1101		1007		912		912		912		912
O2 TANKAGE - CRYO STORAGE	0	0	0	0	0	0	0	0	0	0	0	0
O2 TANKAGE - GAS (repress)	1	36	1	36	1	36	1	36	1	36	1	36
N2 TANKAGE - GAS (FOR REPRESS)	4	120	4	120	4	120	4	120	4	120	4	120
CABIN PRESS & COMPOSITION CNTRLS		182		164		146		146		146		146
CO2 REMOVAL - 2 BED LIOH		33		30		26		26		26		26
LIOH CANISTER STORAGE		159		143		127		127		127		127
TEMPERATURE CONTROL		69		62		55		55		55		55
HUMIDITY CONTROL		502		452		402		402		402		402
FURNISHINGS AND EQUIPMENT		1100		990		880		880		880		880
SEATS, PERSONNEL RESTRAINTS	10	1000	9	900	8	800	8	800	8	800	8	800
INCIDENTAL EQUIPMENT	10	100	9	90	8	80	8	80	8	80	8	80
SUPPORT/INSTALLATION		220		200		179		179		179		179
FLIGHT CREW, WITH EQUIPMENT	2	800	1	300	0	0	0	0	0	0	0	0
PASSENGERS, WITH EQUIPMENT	8	2400	8	2400	8	2400	8	2400	8	2400	8	2400
LIFE SUPPORT CONSUMABLES		272		245		218		218		218		218
O2 - CRYO STORAGE (METABOLIC)		72		65		58		58		58		58
FOOD		120		108		96		96		96		96
POTABLE WATER		80		72		64		64		64		64
Total Weight		9879		9804		11537		10432		13651		10462

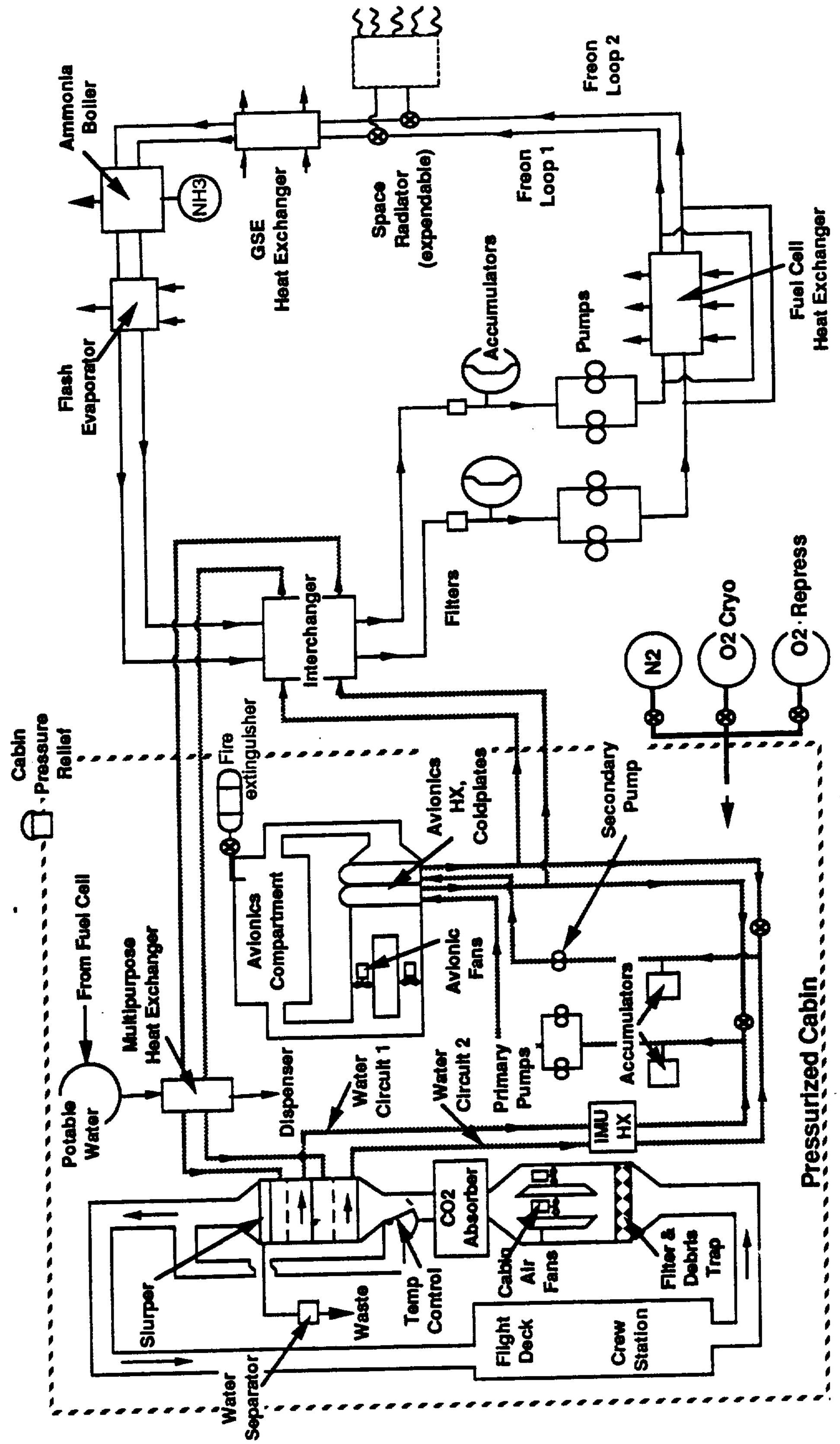


Figure 9.7-1 ECLSS Hardware Schematic

Table 9.7-1 ECLSS Equipment List

Wbs	Item	Qty	Hardware Wt. (Lb)	Consum. Wt (Lb)	Power Watts	Vol Ft3	Description
	Cabin And Personnel System		416				
	O2 Tankage - Cryo Storage	0	0	35			Metabolic Consumpt. (2 Lb/M-day) +20%
	O2 Tankage - Gas (For Repress)	1	15	14		0.82	Repress + Leak (0.38 Lb/Day)
	O2 Gas - Initial Press			14			
	N2 Tankage - Gas (For Repress)	2	60	67		4.73	Repress + Leak (1.26 Lb/Day)
	N2 Gas - Initial Press			63			
	Press Plumbing		12				
	Cabin Press & Composition Cntrls		65		21	2.75	Valves, Vent Relief Valves, Etc
	CO2 Removal - 2-bed Lioh		11			7.20	Lioh Canister Unit - 2 Canister Unit
	Lioh Canister Storage		100			4.20	(20 / 28 M-day)
	Temp And Humidity Control		127		641	12.90	Fans/Separators, Etc
	Trace Contaminant Control		7			0.20	Canister For Impurity Removal
	Ducting, Misc		20				Fans Included In Temp Control
	Equipment Cooling		209				
	Equipment Cold Plates		120			0.48	S= 60 Sf @ 2.0 Psf
	Avionics Cooling Assy		28		188	2.00	Incl Hx, Fans, Ducting
	Imu Heat Exchanger Assy	1	31		50	2.69	
	Plumbing		20				
	Ducting, Misc		10				Fans Included In Temp Control
	Heat Transfer Water Loop		161				
	Heat Exchanger - Potable Water	1	17			0.41	Based On Shuttle
	Primary, Secondary Water Pumps		78		423	2.52	
	Plumbing		30				
	Coolant In Loop - Water		36				
	Heat Transfer Freon Loop		270				
	Heat Exchanger - Water-freon	1	50			0.41	Based On Shuttle
	Heat Exchanger - GSE	1	50			0.41	Based On Shuttle
	Heat Exchanger - Fuel Cell	1	50			0.41	Based On Shuttle
	Freon Pump Package	2	90		264	6.04	
	Coolant In Loop - Freon		30				
	Heat Rejection		222				
	Ammonia Boiler Assembly		45			Tbd	Incl Tank, Heat Exchngr, Valves
	Coolant Tankage - Water		14				
	Flash Evaporator		58	20	73	4.60	Based On Shuttle
	Topping Duct Assembly		78				
	High Load Duct Assembly		27				
	Radiator Panels (On Oms Module)		795				Al H/C Panels With Bonded Tubing
	Coolant In Panels - Freon		30				
	Fixed Panels	2	304				A=134 Sf Ea
	Deployed Panels	2	461				A=134 Sf Ea (134 Sf Ea Side)
	ECLSS Supt/Instl		128				10 % Of Equipment Wt
1.1.14	**Environment - Crew Module**		2201	213	1660	52.77	

Separate listings are made for estimation of interconnecting ducts, plumbing, and wiring. The estimates for most of this hardware were derived from STS systems values, prorated in some cases by the ratio of PLS to STS loads. Consumables estimates were derived from current NASA specifications on crew metabolic loads, taken from the latest Space Station Freedom ECLSS Architecture Control Document (ACD).

9.7.1 Atmosphere Revitalization

The most significant trade conducted for the environmental control subsystem is the assessment of open versus closed-loop for the atmosphere revitalization system. Open-loop systems expend and replace atmosphere while closed-loop systems have some degree of atmosphere reconditioning and reuse. This trade focused on issues such as mission duration, crew size, and future mission plans. As crew size and/or mission duration is increased, the consumables mass goes up which tends to favor the closed-loop systems. Open-loop systems tend to be less complex and thus easier to produce and maintain. A plot of system weight versus mission duration (in person-days) is shown in Figure 9.7.1-1. Included on this plot are the requirements for various PLS missions. As can be seen, the open-loop system is sufficient for the majority of the missions (crew rotation and satellite servicing). For the longer mission, partial water recovery begins to be desirable, however, the number of these missions is not a large enough percentage of the mission model to warrant selection of the more complex closed-loop systems. The open-loop system can be fairly easily upgraded to a closed-loop system if required in the future.

9.7.2 Environmental Control for Equipment

The avionics air loop consists of a single avionics cooling assembly with dual fans and a dual heat exchanger and a single IMU cooling assembly with a filter, triple fans, and a dual heat exchanger. These assemblies circulate cooling air through critical avionics instrumentation located behind the cabin instrument panels but contained within the pressurized cabin volume.

The cooling water loop transports heat from cabin heat loads to the vehicle Freon heat rejection loop. The cooling water loop is critical to both crew and vehicle safety and therefore is redundant. A primary set of pumps provides for coolant circulation and backup. A secondary pump package is included which adds one additional level of

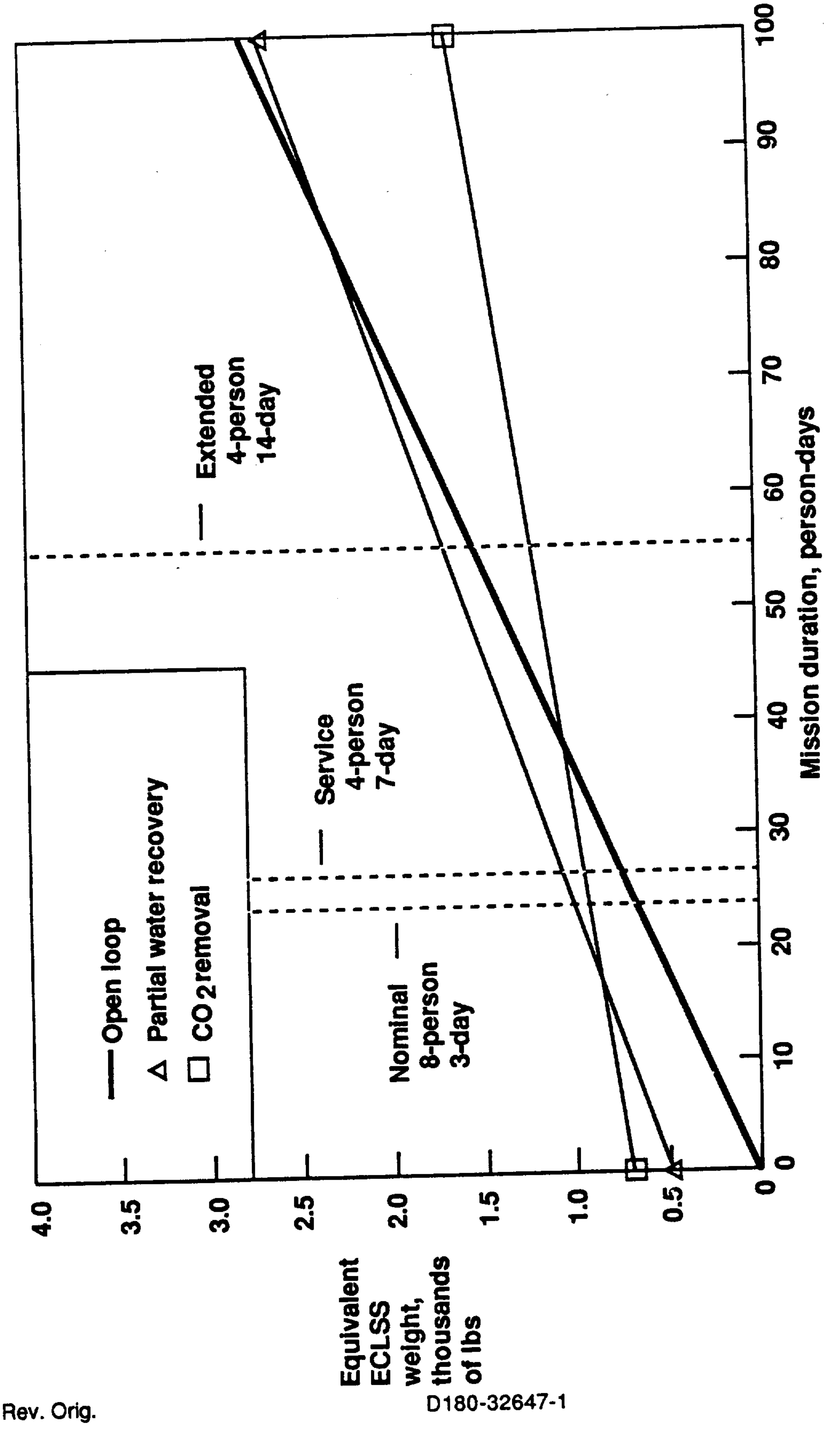


Figure 9.7.1-1 ECLSS Approach Comparisons

redundancy. Accumulators provide for system makeup and pressurization. Additional elements in this loop include multipurpose heat exchangers and avionics cold plates. A multipurpose heat exchanger is used to cool water for the crew water dispenser. If EVA is performed from the PLS, then two additional multipurpose heat exchangers would be required to provide cooling to the liquid cooled ventilated garments (LCVGs) for the two EVA crew persons during donning/doffing and checkout. The Freon heat rejection loop transfers the cooling water and fuel cell heat loads to the vehicle heat rejection devices. The Freon cooling loop is critical to mission completion and crew safety and is therefore redundant. Two Freon pump packages provide circulation, pressure control, and makeup to two independent Freon loops. Each package consists of two pumps, a filter and an accumulator. Cooling water loop heat loads are transferred via a single Freon/water interchanger with redundant water and Freon fluid paths. Fuel cell heat is transferred via a special fuel cell coolant-to-Freon heat exchanger. The fuel cells have their own local cooling loop.

9.7.3 Thermal Rejection

Excess heat, produced by both equipment and metabolic activity, is removed by the ECLSS and is rejected to the surrounding environment. Thermal rejection strategies must account for various phases of the mission which occur in different surroundings. These phases are: pre-launch, ascent, orbital operations, descent, and post-landing. Reducing the amount energy consumed on the vehicle directly reduces the heat load that needs to be removed. In particular, the use of highly integrated avionics can significantly decrease power consumption and hence thermal output. For the technology availability level assumed for this study, and using a mission profile explained in Section 4.2, a thermal profile was produced as Figure 9.7.3-1. Note that the highest levels occur at the beginning and end of the mission. This is due to the fact that the entire personnel complement is on-board and that many avionics and ECLSS devices are operating. A more detailed analysis would show a plot with fewer sharp corners as thermal inertia/reradiation was accounted for, but the total heat load would not vary significantly.

During the pre-launch phase, external thermal control would be provided at the launch site or servicing facility. The GSE would provide coolant (most likely cold Freon) through fly-away disconnects to a heat exchanger in the ECLSS loop (refer to Figure 9.7-1). This conserves PLS expendables usage while waiting in a powered-up configuration for an indefinite launch hold. This stratagem also eliminates the

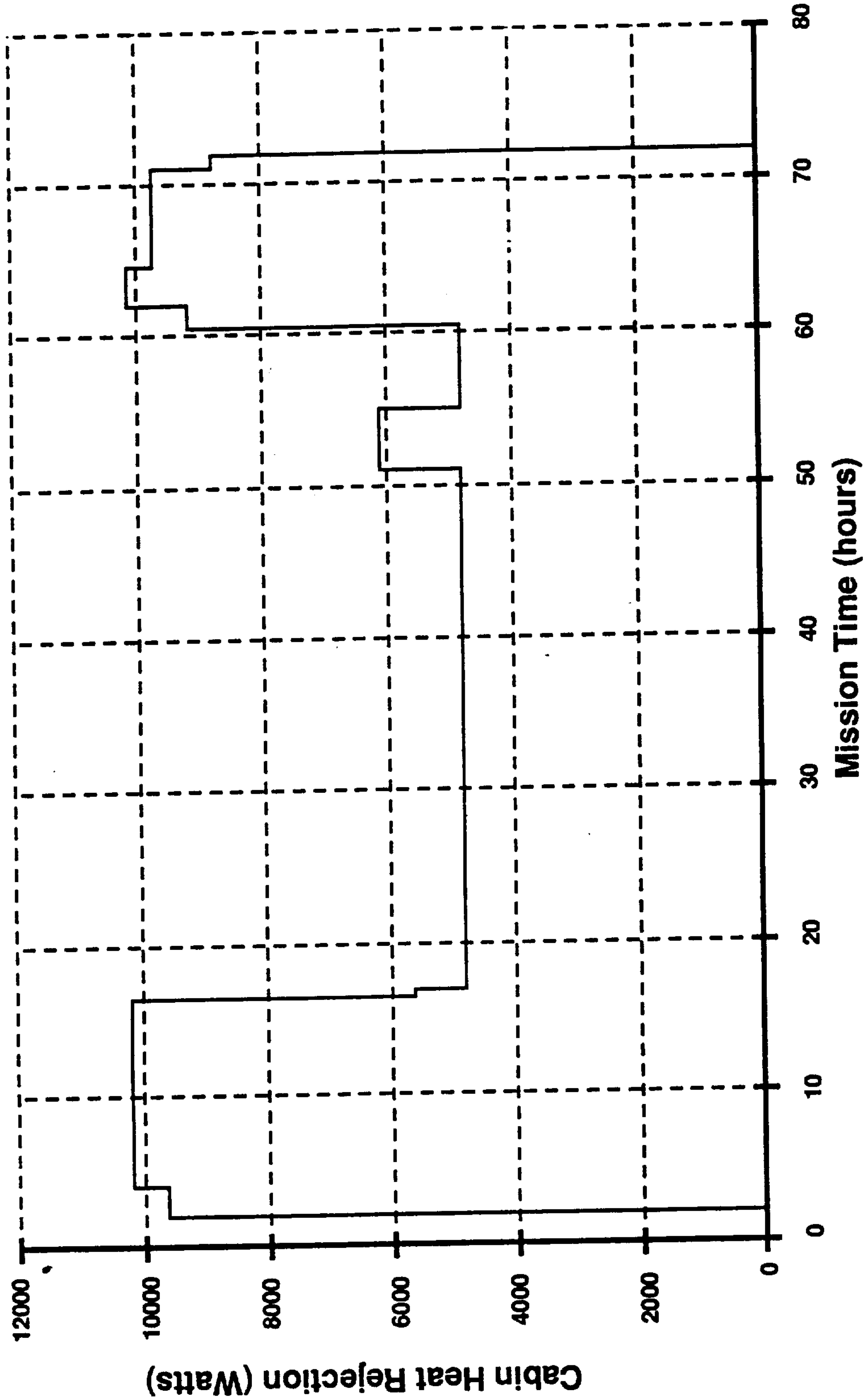


Figure 9.7.3-1 Thermal Profile

possibility for unfavorable interactions between radiated heat or vented vapors and the launch vehicle or launch facilities.

As the vehicle is launched and ascends to its operational orbit (a period of time lasting up to a few hours), the vehicle is subjected to aerodynamic and aerothermal forces that prevent the use of some heat rejection concepts. Deployable devices, for example, would be unacceptably heavy if designed to be robust enough to tolerate dynamic pressure loads. Passive thermal control, or heatsinks, could be used and are close to the present state of the art. Analysis shows that a reasonable passive concept could provide thermal control for a period of time much less than the length of the mission; if such a system were used to its capacity, some other form of thermal rejection would still be required to cover the rest of the mission.

Another type of device, a flash evaporator, has been used successfully on the Space Shuttle. Previous water evaporator experience consists of wick-feed boilers of the type used on Mercury, Gemini, and the Apollo Command Module, and porous plate type sublimators used on the Lunar Module, Apollo space suits, and the Saturn V. All these devices, while meeting reliability expectations, had response, heat load range, and life limitations that led to the Shuttle-type flash evaporator development. Flash evaporation involves spraying water on the walls of a chamber heated by the coolant loop. The chamber is maintained at a saturation pressure low enough for the water to evaporate at a temperature below the desired coolant loop outlet temperature. The generated steam is vented overboard through a sonic nozzle. Water is the preferred fluid for several reasons. First, water has the best latent heat of vaporization per weight per volume of any candidate fluid and therefore minimizes the weight/volume penalty on the vehicle. Secondly, by drawing excess water from the fuel cells (a byproduct of power production), a synergistic reduction in total vehicle mass is realized. Thirdly, water is non-toxic and is relatively benign when vented to space in the vicinity of adjacent spacecraft.

The selected ascent thermal control uses a water flash evaporator. To reach the necessary low operating pressure, the vehicle must be above 140,000 feet altitude. During a typical boosted trajectory, it takes about two minutes to reach this height and sufficient thermal inertia is assumed to passively control the thermal environment until the flash evaporator can be activated.

During the orbital operations flight phase, the operating environment is significantly different although the average heat load profile (see Figure 9.7.3-1) tends to be lower. In a weightless, near-vacuum situation, several options for heat rejection are available. A flash evaporator would function adequately, but the additional consumable weight (water) becomes considerable for longer missions. Also, the outgassed steam, although benign compared to other fluids, can negatively affect other spacecraft. In fact, current SSF operating rules would probably not permit this venting while in the vicinity of the station.

The other category of thermal control schemes radiate waste heat to the low temperature of black space. There have been many vehicles that have used radiators, from simple conductive cooling fins to deployable panels (such as the STS Orbiter). Radiator designs are relatively simple, reliable, and robust. To maximize performance, a high reflectivity, high emittance coating is required (such as white paint). The PLS has a fairly high waste heat to surface area ratio compared to previous manned spacecraft; this is because of the number of personnel in a vehicle sized without payload bay or main propulsion sections. Figure 9.7.3-2 compares typical values for the amount of radiated energy per square foot of radiator. Based on this data, a conservative value of 15 W/ft^2 was selected which leads to a requirement of at least 600 ft^2 of radiator area (actual size is larger to account for interference and inefficiencies related to vehicle/background orientation). This area is larger than the entire conical surface area of the biconic PLS. Scaling the vehicle to use a fixed surface radiator would require a linear scaling of almost 140%. Reusable, deployable rigid panels could be used but would increase complexity and present a flight safety issue in that they must be completely retracted and secured for reentry. A failure of even one latch could result in the loss of the radiator, or worse, control of the vehicle. Expendable radiator concepts (discarded at reentry) would alleviate these safety concerns and would negate the vehicle size and landing weight issues associated with the large PLS radiator size. In addition to metallic panel type radiators, one could use an inflatable device using ECLSS air as a working fluid. Such a system promises to be extremely low cost, low stowed volume, and very lightweight but is as yet an unproven concept though worthy of exploration. The selected design for PLS is an expendable metallic radiator that also serves as part of the launch vehicle adapter. This approach was used in the Gemini program. Because of the large area required, a

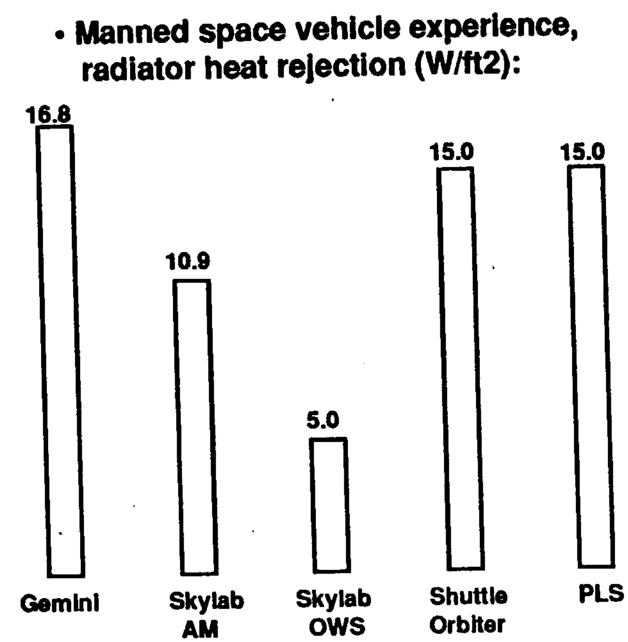


Figure 9.7.3-2 Typical Manned Specacraft Radiated Heat Rejection

simple set of one-shot deployable panels (see Figure 9.7.3-3) was incorporated, effectively tripling the surface area for a given length.

The descent phase is similar to the ascent phase in that aerodynamic and aerothermal forces dominate external surface design. A significant difference though, is the time spent in the atmosphere (up to half an hour on descent). Water flash evaporators will not function below about 140,000 feet. Heat loads are large for passive systems of reasonable size. On the Space Shuttle, an ammonia boiler is used to provide cooling for the last ten minutes of flight and for about 15 minutes after landing until GSE can be connected. Ammonia, while having a latent heat of evaporation only half that of water, is the next most efficient coolant by weight and volume. Alternative fluids have been explored but are either inefficient and require large storage volumes or are environmentally hazardous to release (such as chloroflourins). Why not use the same ammonia boiler for ascent? Ammonia is toxic and can be stored sealed until the end of the mission to minimize potential hazards. This ammonia flash evaporator system has been selected for the descent phase.

In the post landing phase, there is still a requirement to reject waste heat. Some subsystems (communications, ECLSS, etc) may be kept on for hours. Additionally, depending on the vehicle's thermal protection system concept, a significant amount of heat has been absorbed on reentry and will reradiate after landing, even if all systems are shut down. The capability for the structure and secondary structures to safely absorb this heating without auxiliary GSE remains to be determined.

9.7.4 Fire Detection and Suppression

Fire poses a significant hazard in the confined space of the pressurized compartments of a PLS. Careful selection of materials, insulation, and isolation will reduce the risk of fire damage. In the event of even the smallest fire or smoldering, the risk of inhalation of toxic combustion plastics (such as wire insluation) could quickly harm the crew. Appropriate warning and action are required.

The smoke detector for the avionics equipment will be an ionization type device located within the pressurized avionics space. It will signal the crew as to the location of any fire hazard behind the avionics panels. Since the crew compartment is a wide open space and will be occupied all of the time, detection of smoke or flame in this area will be dependent upon crew alertness. Suppression will consist of a single

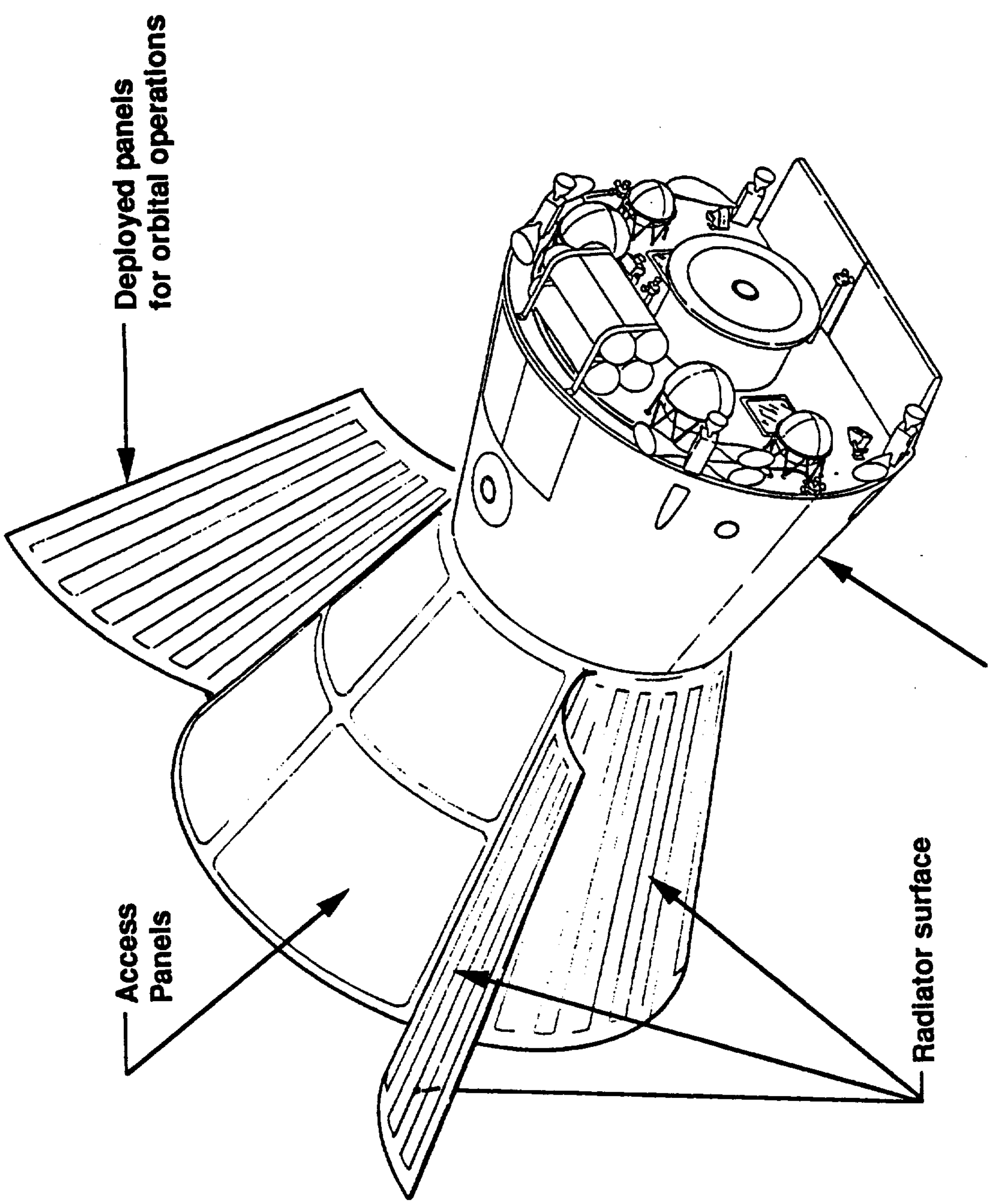


Figure 9.7.3-3. Deployable Radiator Concept

crew-operated fire extinguisher used directly on a source of fire in the crew compartment and used indirectly through fire extinguisher ports provided in the instrument panels in the case of a fire within the pressurized avionics compartment.

9.8 Personnel Provisions

Personnel provisions consist of the equipment and miscellaneous items associated with manned flight. Most of the hardware is based on existing technology as embodied by the STS Orbiter or SSF designs. An equipment list for all the personnel provision items is given as Table 9.8-1. Descriptions of personnel provisions used on the Shuttle can be found in References 20 and 21.

9.8.1 Food Management

Previous manned spacecraft have incorporated a range of food management from food paste in tubes to the Space Station's comparatively extensive galley provisions.

For the crew rotation mission (DRM 1), the passengers are typically on board for only 8-14 hours. With concurrence from surveyed astronaut crews, the only food provisions for this mission will consist of "cold" food, similar to a brown bag lunch. A variety of food types would be provided and each crew member would select their individual meals from a finite menu of food items. The allocation per person is nominally 4 lbm with 8 lbm per person provided as a contingency. Potable water would be available either for drinking or food hydration.

For the long duration missions, nutrition and morale dictate that a more complete food service be provided for. A small galley, similar to that used on the STS Orbiter would weigh 166 lbm and take up 9.0 ft^3 of space. Additionally, figuring 4 lbm of food/man/day, up to 128 lbm of food could be carried along with the associated locker space.

9.8.2 Waste Management/Personal Hygiene

Effective waste management and hygiene in zero gravity has challenged designers from the earliest days of spaceflight. In the future, typical PLS mission will have mixed gender crews with little experience wearing confining flight suits for extended periods. Integral urine bags and/or feces bags will not be acceptable. Similarly, the volume weight, and complexity of a SSF-type lavatory/wash facility would be prohibitively large.

Table 9.8-1 Personnel Provisions Equipment List

WBS	ITEM	QTY	Hardware Wt. (lb)		Consum. Wt (lb)	Power kW	Vol ft3	Description
	Food Management			117	128		26.40	Food Storage Lockers
	Water Management			85				
	Water Storage Tank		50		80		6.75	For Potable Water Storage
	Handwash - Wet Wipes		2				0.24	
	Water Dispenser		23					Water Dispenser Only
	Plumbing, Valves, Etc		10					
	Waste Management			80				
	Waste Water Tank		50				6.75	
	Commode System Scar		15				21.00	Installed for service mission only
	Emergency Waste Collection		15				1.00	Shuttle Type
	Fire Detection / Suppression			13				
	Smoke Detectors		7					
	Fire Suppression Tank		6			4		Includes Suppressant
	Furnishings And Equipment			1100				
	Seats, Personnel Restraints	10	1000					Incl Flight Seat, Impact Attenuation
	Sleep Stations		0					Not Required
	Incidental Equipment	10	100					Storage For Personal Effects
	Support/Installation			140				10
1.1.15	**Other - Personnelprovisions**			**1535**	**208**	**4**	**62.14**	
1.1.17	Flight Crew, With Equipment			600				
	Crew Members / Personal Effects	2	600					90th Percentile + 107 Lb Ea.
1.1.17	Passengers, With Equipment			2400				
	Personnel / Personal Effects	8	2400					90th Percentile + 107 Lb Ea.
	Non- Cargo Items			**3000**				

For the shorter duration crew rotation mission, no lavatory/waste treatment facilities would be included. A combination of relatively short occupancy times and appropriate pre-flight diet should justify this decision. Hygiene would be provided for by using pre-moistened wipes (no plumbing required although as plumbing scar is included).

During the longer missions (carrying four personnel for up to 7 days), proper sanitation is necessary to ensure crew health. A partitioned-off modular lavatory/hygiene station would be added. This lavatory, weighing about 165 lbm and occupying 28 ft^3 (including the waste tank), is similar to that found on the Space Shuttle. If the PLS is away from other spacecraft, excess waste could be vented overboard should the waste tank become full.

A stowable shower, like that on Skylab, could be included for long missions, but a cursory look shows the scar weight to be 400 lbm including 115 lbm of expendables, for a seven day, four person mission.

9.8.3 Furnishings and Equipment

PLS furnishings include crew and passenger seats, sleep stations for longer duration missions, and personal equipment stowage provisions. Personnel seats are similar to the Shuttle Orbiter seats and provide restraint and impact attenuation for all phases of flight. They can be stowed during flight and removed for flights with fewer personnel. The pilot and copilot seats allow for extra adjustability, much like the STS seats. Average seat weight allowance is 100 lbm. The seats also include a Personnel Emergency Air Pac (PEAP), similar to the STS design. The arrangement of seats for the crew rotation mission is shown as Figure 9.8.3-1. The line abreast configuration permits the maximum accessibility to the hatches in the event of an emergency egress.

Sleep stations are provided for longer mission durations but not for the crew rotation mission. Each sleep station includes a privacy enclosure and sleep restraint and weighs 128 lbm.

9.8.4 Storage

Volume for storage is an important consideration. Proper stowage prevents floating hazards and helps maintain the proper center of gravity. Appropriate access can reduce offloading/on loading times.

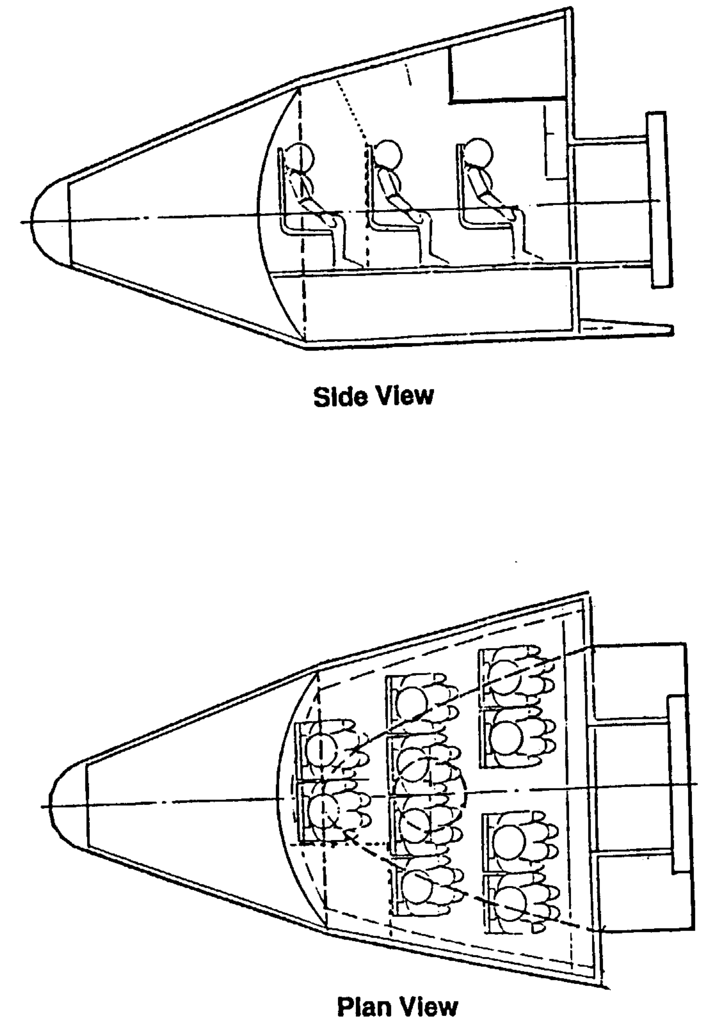


Figure 9.8.3-1. Seating Arrangement for 10 Person Crew Rotation Mission

An allocation of 300 lbm/person was given. Average personnel weight is 193 lbm. This leaves about 107 lbm for personal effects and flight suit. Density of these items is postulated to run between 10 lbm/ft3 (typical of a packed backpack) and 40 lbm/ft^3 (typical parachute packing density). Picking a value of 20 lbm/ft^3 implies a requirement for 55 ft^3 for total personal stowage for the crew rotation mission.

Other storage is required for LiOH canisters (8.0 ft^3 in a rack), food (29.0 ft^3) and sanitary wipes (1.0 ft^3).

For the longer missions, stowage requirements would increase. Without further definition, it is assumed the same volume (93 ft^3) is available and sufficient. The lavatory and galley modules would contain appropriate consumables storage within their given volumes.

9.9 Landing and Recovery System

After flying a controlled descent from orbit, the PLS will need to decelerate and land safely. This terminal phase of the flight involves several stages, each requiring separate hardware and procedures. The problem is one of energy management - how to dissipate the kinetic energy in the most reliable, cost (and weight) effective manner while minimizing the deceleration loads on the personnel.

In this section, each flight phase will be discussed separately (including a contingency water landing), although each is interrelated.

9.9.1 Descent Phase

Descent phase devices are designed to address three key issues: deceleration, dispersion, and stability. In addition, the requirements for low cost, minimum weight, and minimum configuration impact (e.g. volume) must be accounted for.

Deceleration is initiated at high speed, typically at or before terminal velocity, and should result in a significant reduction in vertical velocity. The terminal flight phase involves a final deceleration to attenuate the ground impact force (discussed in detail in the next section). At all phases of the descent, there should be no adverse deceleration forces on the human occupants.

The second key issue is the minimization of dispersions. An operational PLS should have sufficient control authority and guidance and navigational tools to account for a range of off-nominal trajectories or atmospheres (i.e. wind) and still arrive at the designated landing site. Overflight of populated land masses will require this capability to react to varying situations encountered during entry.

The third major issue involves flight stability. Many reentry shapes are marginally stable or even unstable in the supersonic/transonic flight regime. Even for designs with positive stability, it is very important that the vehicle is stable when other landing devices may be deployed or the crew may be required to perform some "piloting" function. Crew comfort and impact attenuation hardware design also dictate the need for a stable landing attitude.

Many options for descent phase hardware have been built and flown (see Reference 19). The following paragraphs describe the major options. The selection of a preferred concept must also include the concept for impact attenuation.

Aerodynamic, high drag devices would include parachutes, inflatable ballutes or balloons, and fold-out speed brake panels. There have been many designs that have flown using these techniques. These devices tend to be mechanically very simple and pack into fairly dense containment volumes. When fully deployed, they provide a stable, predictable descent. The issues associated with non-rigid, high drag devices are related to two areas: the reliability of the deployment sequence and; the dispersions due to winds. The deployment sequence is a complex interaction of aerodynamic forces based on vehicle attitude, velocity, dynamic pressure, and the local geometry of the unfurling drag devices. Inflatable devices also have the concerns related to material leakage integrity and the additional inflation hardware.

Other deployable, semi-rigid structures could be used to "fly" the vehicle; that is, to decelerate and steer the vehicle by having a "no wings", low L/D shape emulate a lifting vehicle. Devices in this category would include fold-out wings, Rogallo wings (such as the one envisioned for Gemini), and deployable rotor assemblies. These devices tend to be very difficult to integrate into the design. They tend to be mechanically complex and a fail-safe mechanism is difficult to integrate.

An all propulsive deceleration system, or retrorockets, could also be used. There have been several planetary vehicles, most notably the Apollo Lunar Module, that employed

this technique. Earth landing vehicles using all propulsion have been studied extensively (such as for a vertical takeoff, vertical landing single stage to orbit vehicle), but have not been used operationally. The concept employs a rocket(s) pointed into the direction of flight to fire and slow the vehicle, finally firing immediately before ground impact to reduce the vertical velocity to zero.

In theory, retrorockets should provide a compact system resulting in the least impact loading on crew or hardware of any option. Modern radar or Lidar altimeters would enable precise timing of impact attenuation burns. On the negative side, there are several issues concerning such a system that would significantly affect the DDT&E cost and schedule. First, there is the perceived risk of "falling" rapidly towards the ground and reliably starting up the thrusters in time to arrest the descent. With modern sensor technology, it is possible to sense an engine failure and initiate the appropriate corrective action. Another issue is the protection of the thrusters and propellants from reentry heating. Propellant acquisition could be an issue, depending on the selected type of propellant, especially after a longer mission where boiloff has occured. The thrusters must either be protected (at issue is a trade of the complexity of a "door" mechanism or the expense of replacing expendable covers) or the vehicle must be reoriented for a braking burn (an unlikely solution for consistent crew orientation). In summary, while it appears that all of the issues associated with an all propulsive system could be resolved, the configuration impacts would be significant.

9.9.2 Impact Attenuation

There are a variety of strategies for impact attenuation, most all of which have been built and tested in the past. Figure 9.9.2-1 depicts a top level option "tree". All of the terminal deceleration options fall under one of two stategems: either reduce the vertical velocity before ground contact, or dissipate the energy of impact over some finite distance. Some aerospace systems (aircraft most notably) use a combination of both techniques.

Each of the individual techniques for impact attenuation are discussed in this section; select combinations (the most promising based on engineering judgement) were evaluated further. All the concepts adhere to a philosophy of operational robustness and rely solely on onboard systems - no specialized ground based landing provisions should be required.

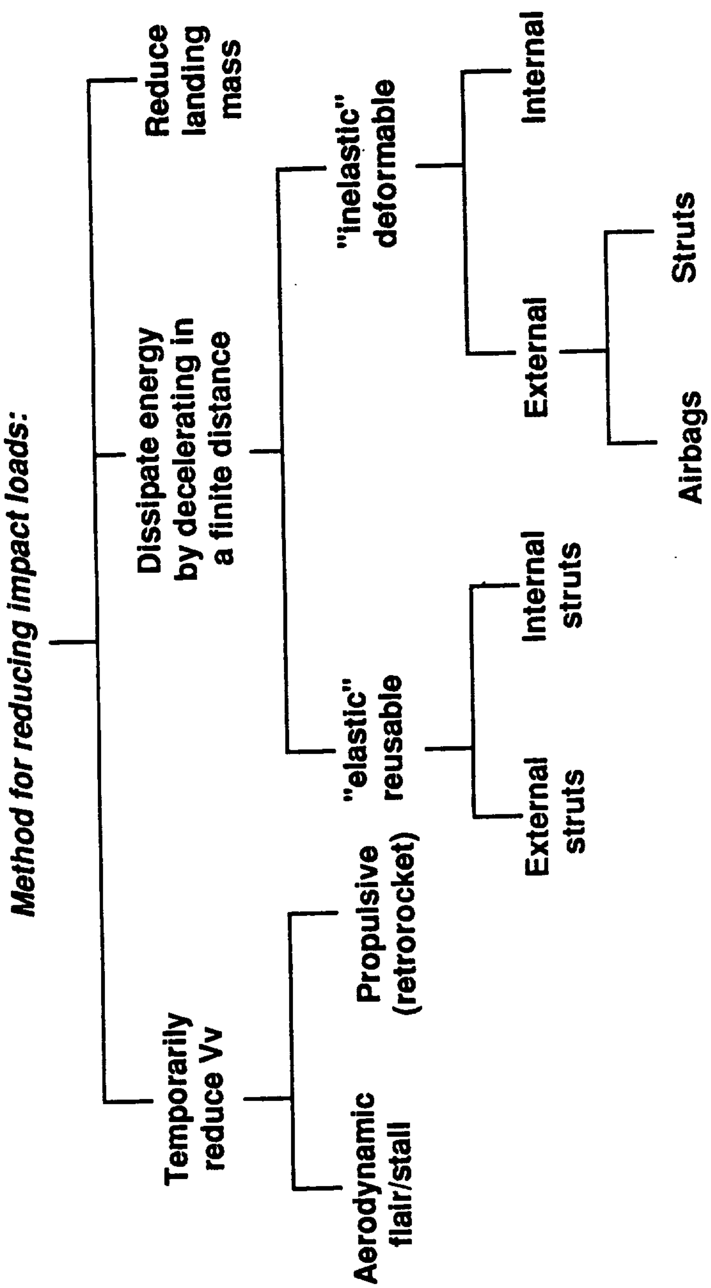


Figure 9.9.2-1 Impact Attenuation Techniques

There are two general methods for reducing the terminal vertical velocity before ground impact. One would entail firing a propulsive system to produce a thrust opposite from the direction of flight. The other is to aerodynamically change the low speed L/D ratio to decrease velocity.

It is unlikely that the addition of distinct aerodynamic devices solely for use during the impact attenuation phase could be justified as this would add the weight and complexity of an additional subsystem. However, when the design already incorporates aerodynamic descent devices, such as fold-out wings, lifting parachutes, or rotors, the additional control for aerodynamic modulation is feasible.

In the case of a rigid fold-out wing, high lift devices, such as flaps, would be necessary. Conceivably, a gas generator could produce hot gas for a blown flap that would dramatically increase lift. The drawbacks of the horizontal runway landing concepts include the mechanically complex mechanisms required and the requirement for high speed landing gear (with brakes). The flight test program is fairly involved, and if a pilot is to have control, forward vision and appropriate controls and displays are also required. The major issue, though, is the horizontal landing velocity. Figure 9.9.2-2 depicts the classic relationship between the wing area and touchdown velocity for a range of lift coefficients. For a fold-out wing, it is very difficult to configure a large wing area. In an abort, water "ditching" horizontal velocities above about 80 kts will probably result in structural failure, reducing the chances for crew survival. High touchdown speeds also reduce decision times if a human pilot is required to perform critical flair maneuvers. Even with high lift devices, the fairly blunt shapes associated with low hypersonic L/D vehicles have a very high subsonic drag, which reduces subsonic L/D, resulting in a poor "airplane" for runway landing.

For a non-rigid lifting surface, it is possible to deploy large wing areas. An aerodynamic flair or stall can be effected by simple trailing edge deflection and will significantly reduce the vertical and horizontal velocity (see Figure 9.9.2-3). The issues associated with this technique involve the control system reliability, and the need to accurately sense altitude to initiate a properly timed flair.

Using a retrorocket for impact attenuation in combination with another deceleration device is an attractive alternative. Several aerospace programs have employed this technique (such as the Soyuz capsules). A one-shot retro rocket package initiated

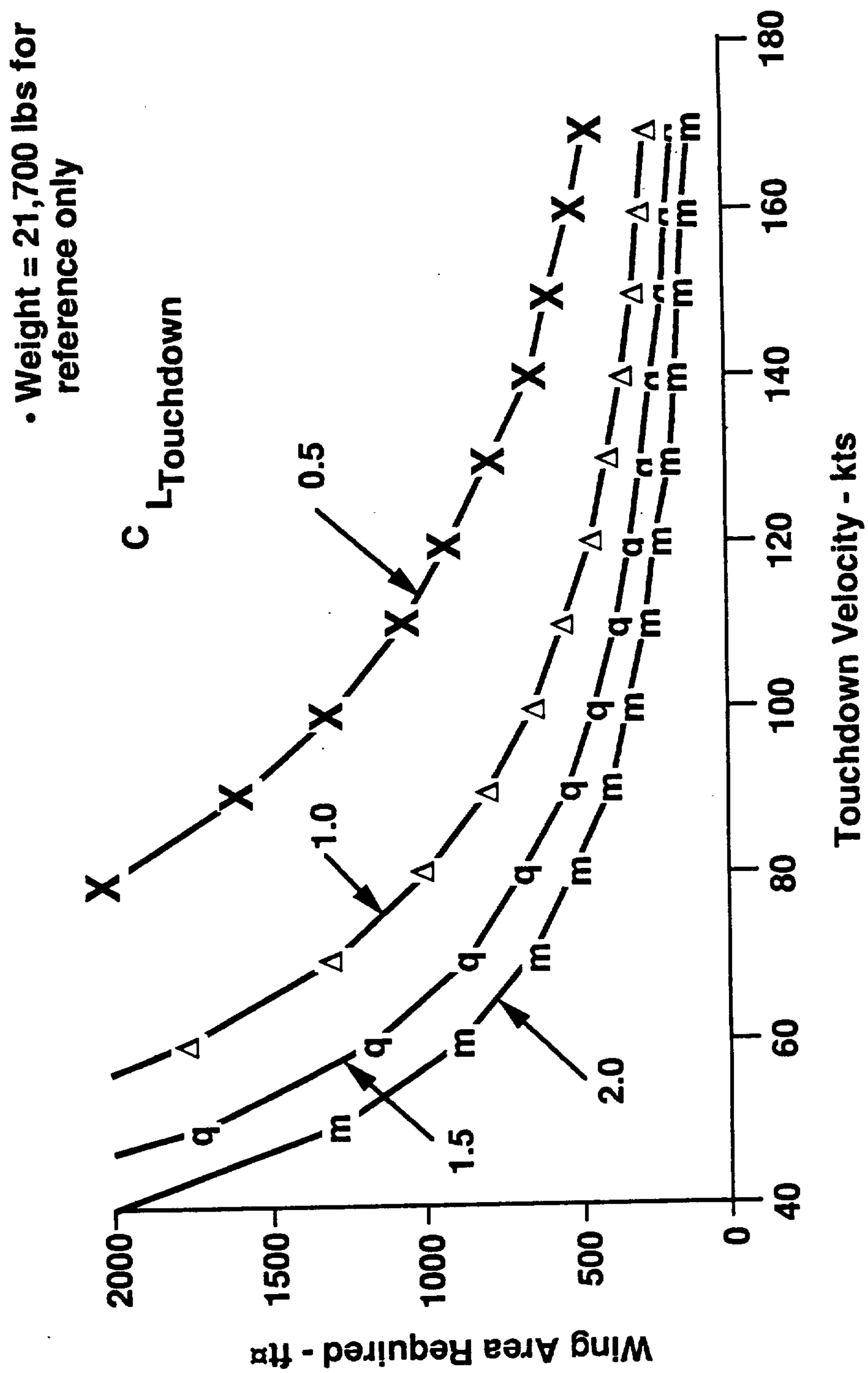


Figure 9.9.2-2 Wing Area Versus Touchdown Velocity

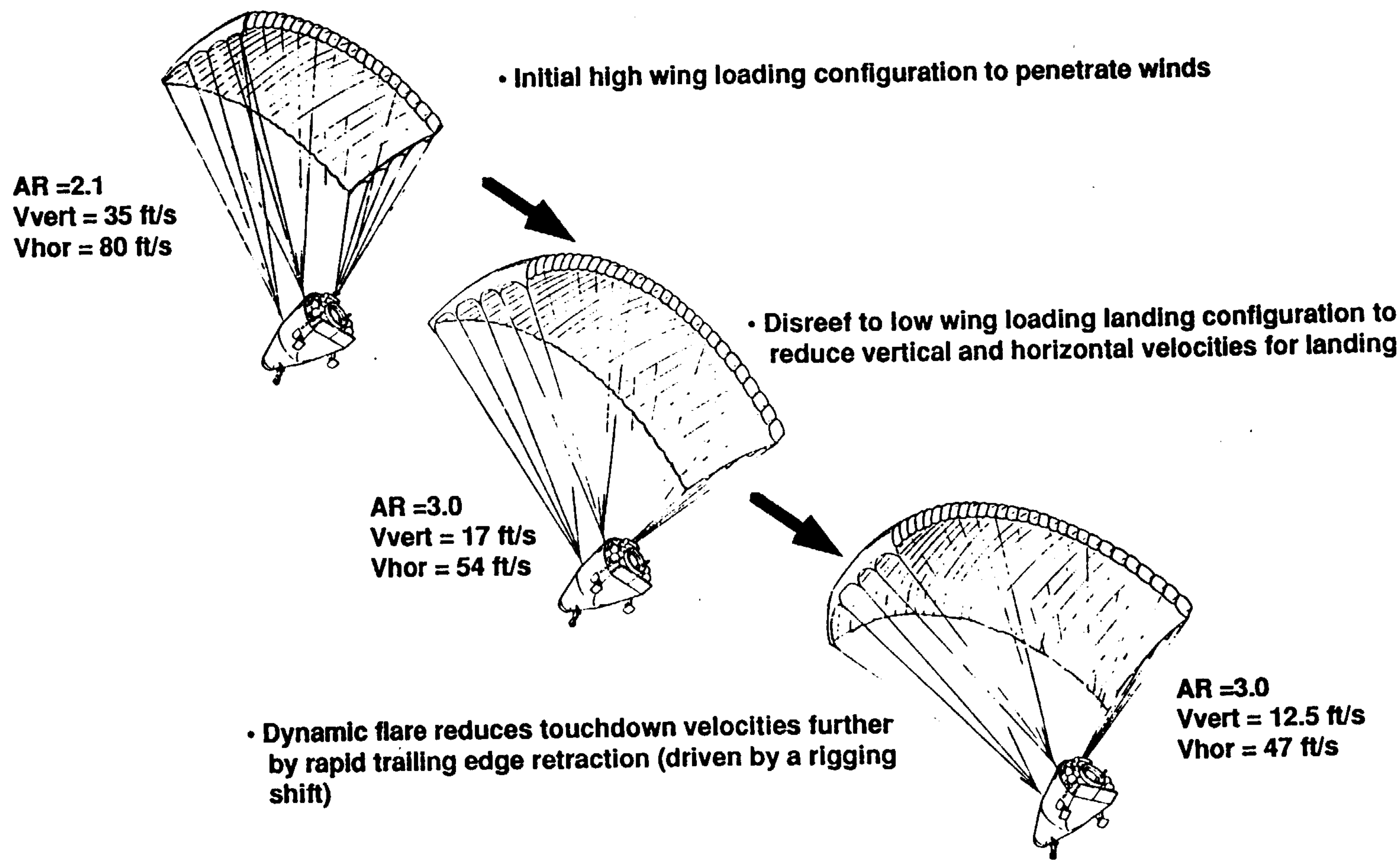


Figure 9.9.2-3 Parafoil Flair Characteristics

during the last few feet of descent (Soyuz used a weighted line to contact the ground, Gemini explored a telescoping rod, modern radar altimeters or Lidars would also work) can very effectively and reliably eliminate most or all of the vertical velocity. On the basis of weight alone, this option for impact attenuation is very promising. The issues are similar to the all propulsive systems. One difference, however, is that while the all-propulsive system would employ some control (probably gimballed engines), the propulsive impact attenuation devices would probably be fixed (to reduce overall complexity) and would therefore have no ability to correct for ground winds, slope or other side-loading conditions. As a result, the vehicle must be designed to roll or tumble; the additional robustness may cancel out any weight savings resultant from using a retrorocket and the impact on crew safety and comfort may be unacceptable. Most importantly perhaps, is the issue associated with the loading and handling of the propellant/ordnance for the system. Whether the system is expendable (i.e. solid propellant) or reusable (probably storable bipropellant) there would be a significant impact on ground processing safety to handle these embedded devices.

There are many methods of energy dissipation that have been used on past aerospace programs. All aircraft, for example, incorporate a stroking strut as part of the landing gear. Recoverable drones have used airbags, and planetary spacecraft have used retrorockets. The optimum solution for PLS may use several techniques for energy dissipation.

Crushable or deformable materials offer a low development and hardware cost option that is simple, reliable, and effective. These materials could be incorporated into the seat design, internal to struts, between the contact area and the primary structure (for example, the outside skin and the pressure vessel), or, any combination of these locations could be used. The most common materials used are foams, honeycomb, or deformed sheet metal. The issue involved with these materials is one of replacement. The reusable PLS capsule would require additional refurbishment actions and could actually cost more to operate than the savings resulting from the simplicity of the landing system.

Stroking struts provide a controlled, compact deceleration. The struts could be external, as in a conventional aircraft landing gear, or internal (either between the contact point and the pressure vessel or as part of the seat supports, much like Apollo). A fixed chamber is attached to the vehicle, and a sliding piston moves inside the chamber, dissipating energy to either a fluid or a crushable solid. When used

externally, a ground contact device, typically a wheel or a skid/pad, is used to spread the load over a much larger area than the strut. The size of this device can be very large, depending on the design soil bearing strength. Another issue is the protection of the strut during flight - the mechanisms and fluids (including air in tires) need to be protected from aerodynamic forces and aerothermodynamic heating during reentry. Typically, a cutout, or "wheel well" is recessed into the body and a cover (usually a hinged door) is opened to release the strut at the last phase of flight. This increases the structure/mechanisms complexity and weight.

Inflatable airbags have been used on a number of previous vehicles, most often with recoverable drones. Airbags pack efficiently and can utilize a variety of landing terrain and soils. In the past, airbag designs were fairly intolerant of horizontal landing velocities and roll over was a problem. With staged deflating bags, modern applications (such as envisioned for the ALS P/A module) are more robust. The issues related to airbags are primarily associated with the inflation and integrity of the airbag. Also, for some configurations, it is difficult to configure the airbags where there is a solid surface to react against.

A weight comparison of selected recovery system options is shown as Figure 9.9.2-4. Note that most of the options are of similar mass.

9.9.3 Water Impact and Floatation

With a dry land landing as a primary PLS recovery mode, the terminal descent and impact attenuation hardware are designed by the requirements related to "hard" landings. There are contingency operations, particularly after a launch abort, where a water landing is unavoidable. Because of the problems associated with immersing hardware in salt water, the vehicle may or may not be salvageable for reuse, however, the water impact must be survivable.

Water landing can act to reduce the impact deceleration by a gradual stop over a short distance. On the other hand, impact velocities on the water can produce very high values of dynamic pressure, resulting in structural failure. Vehicles designed for a horizontal runway landing vehicles usually cannot reduce their impact velocity in a water "ditching" (except with very high lift devices or auxiliary parachutes) to a level that is structurally survivable. The Shuttle Orbiter, in fact, would probable not survive a ditching (Reference 23).

Configuration	Comments	Landing Velocities ~ fps (vertical/horizontal)
Parachutes only	Cluster of 3	22 —
Parachutes + Bungee	Same + Bungee	10 —
Parachutes + Retro	Same + Retro	0 —
Autogiro	Foldable autogiro + parachute back-up	0 —
Rocket Motor	Mars lander concept	0 —
Parafoil only	Back-up parafoil	10 25
Parafoil + Retro	Back-up parafoil	5 25
Rogallo	Back-up parachute forward vision	0 65
Fold-out Canard + Jet Flaps	Gas generator forward vision	0 135
Fold-out Canard	Back-up parachute forward vision	0 270
Fold-out Delta	Back-up parachute forward vision	0 335

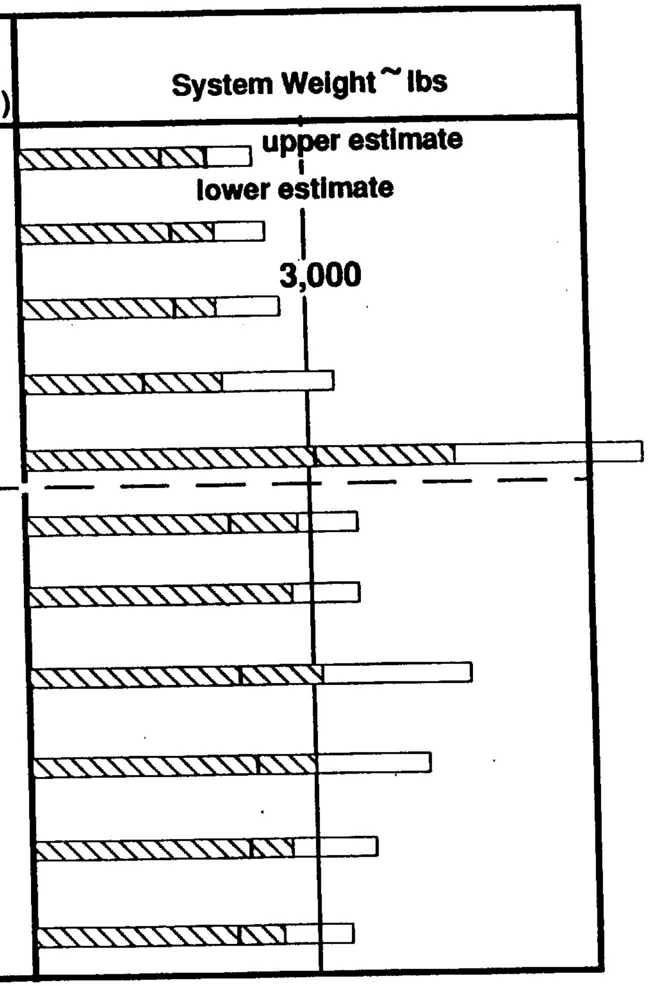


Figure 9.9.2-4 Recovery System Weight Comparison

The loading or water impact is a function of many factors such as shape, velocity, entry attitude, and wave action. Table 9.9.3-1 defines the various sea states. (The PLS should be able to tolerate sea state 5 if it is to survive the majority of probable water landings.) The hydrodynamics of water impact is a complex balance of momentum, buoyancy, and drag, which fortunately can be approximated accurately with a less than complete model. Physically, at entry (while the forward part of the vehicle is wetted), the PLS imparts a physical, principally transverse velocity to the water, and then the flow separates from the body with the generation of a cavity. Air rushes in to fill the void. Later, the splash forms a dome which closes over the entry point of the body and seals the cavity from the air above. When this surface closure (or seal) occurs, the cavity usually is expanding so that the pressure in the cavity decreases. The water pressure being greater than that in the cavity, the cavity is pushed down into the water and travels down with the body into the water. The pressure differential forces the walls of the cavity to accelerate inward to collapse, leaving the body fully wetted. At this point, the cavitation can be ignored in the analysis and the bodies buoyant force and downward momentum are eventually balanced before the rebound to the surface occurs.

The shape of the vehicle affects the build up of drag and the buoyancy force over time as the vehicle penetrates the water's surface. In Figure 6.0-9 it was seen that a "pointier" shape such as the biconic penetrates the water with lower g's that a flatter bottomed entry. Figure 9.9.3-1 shows the effect of the same shape entering the water at different attitudes. The recovery system, in this case the parafoil, should therefore be designed to allow the PLS to hang in an attitude best suited for water entry. In this case, that probably would entail cutting some of the support risers after the flair maneuver; the vehicle would then swing into a "vertical" orientation for water entry.

The wave shape will also determine the water entry dynamics. On Figure 9.3.3-2, it can be seen that in high sea states, the rapid moment produced when striking the local wave at an unfavorable attitude can be significant.

Once the vehicle has come to a stop, it will float at an attitude with the pointed end slightly down into the water. This will help ensure both hatches remain out of the water. Auxiliary floatation bags, such as righting bags, should not be necessary but can be housed in the parachute bay. Further analysis would be required to determine

Table 9.9.3-1 Sea States (Page 1 of 3)

Sea State Code	Beaufort Wind Force Code	Wind Velocity (Knots)	Description: Sea Far From Land	Description: Sea Near Coast	Description: Land	Avg. Particle Velocity (Ft/Sec)	Avg Wave Velocity (Knots)	Avg. Wave Height (Ft)	Avg. Wave Length (Ft)	Avg. Period (Sec)	Min. Fetch (nml.)	Min. Duration (Hrs)
0	0	0	Sea like a morror	Calm	Calm, smoke rises vertically		0	0	0	0	0	0
	1	1-3	Ripples with the appearance of scales are formed but with out foam crests	Fishing smack just has Steerage way	Smoke drift indicates wind direction but valves do not move		1-2	0.05	0.83	0.5	5	0.3
1	2	4-6	Small wavesiets; still short but more pronounced; crests have glassy appear-ance but do not break	Wind fills the sails of smacks which then travek at about 1-2 miles per hour.	Wind felt on face; leaves rustle; valves begin to move	1	3-4	0.18	6.7	1.4	8	0.7
2	3	7-10	Large wavelets, crests begin to break; foam of glassy appearance; perhaps scat-tered white horses	Smacks begin to careen and travel about 3-4 miles per hour.	Leaves small twigs in constant motion; light light flags extended.	2	5-7	0.74	23.5	2.7	9.9	2.1
3	4	11-16	Small waves, be-coming larger; fairly frequent white horses.	Good working breeze, smacks carry all canvas with good list.	Dust, leaves, and loose paper raised up, small branches move.	3	8-10	2.05	55.5	4.0	27.5	5.1
4 5	5	17-21	Moderate waves, taking a more pronounced long form; many white hourses are formed chance of some spray.	Smacks shorten sail.	Small trees in leaf begin to sway.	4	10-15	4.37	100.0	5.4	65	9.2
6	6	22-27	Large waves begin to form; the white foam crests are more extensive everywhere (prob-ably some spray).	Smacks have doubled reef in mainsail; care required when fishing.	Larger branches of trees in motion; whistling heard in wires.	5	15-20	8.05	181.0	6.9	137.5	14.5

Table 9.9.3-1 Sea States (Page 2 of 3)

Sea State Code	Beaufort Wind Force Code	Wind Velocity (Knots)	Description: Sea Far From Land	Description: Sea Near Coast	Description: Land	Avg. Particle Velocity (Ft/Sec)	Avg Wave Velocity (Knots)	Avg. Wave Height (Ft)	Avg. Wave Length (Ft)	Avg. Period (Sec)	Min. Fetch (nml.)	Min. Duration (Hrs)
6												
7	7	28-33	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. (Spin drift begins to be seen).	Smacks remain in harbor and those at sea lie-to.	Whole trees in motion; resistance felt in walking against wind.	6-7	20-25	13.75	251.3	8.6	285.0	23.5
8	8	34-40	Moderately high waves of greater length; edges of crests break into spin drift. The foam is blown in well-marked streaks along the direction of wind. Spray affects visibility.	All smacks make for harbor if near.	Twigs and small branches broken off trees; process generally tapered.	8-9	25-30	23.20	379.4	10.5	552.0	36.2
	9	41-47	High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll visibility affected.		Slight structural damage occurs, slate blown from roofs.	10	30-35	35.67	538.6	12.5	966.7	52.0
9	10	48-55	Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind On the whole, the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility is affected		Seldom experienced on land; trees broken or uprooted; considerable. Structual damage occurs.	11-12	35-40	51.60	709.2	14.6	152.8	72.2

Table 9.9.3-1 Sea States (Page 3 of 3)

Sea State Code	Beaufort Wind Force Code	Wind Velocity (Knots)	Description: Sea Far From Land	Description: Sea Near Coast	Description: Land	Avg. Particle Velocity (Ft/Sec)	Avg Wave Velocity (Knots)	Avg. Wave Height (Ft)	Avg. Wave Length (Ft)	Avg. Period (Sec)	Min. Fetch (nml.)	Min. Duration (Hrs)
9	11	56-63	Exceptionally high waves (small and medium sized ships might for a long time be lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility is affected.		Very rarely experienced on land; usually accompanied by widespread damage.	13-14	40-45	68.50	947.5	16.7	230.0	94.5
	12	64-71	(Hurricane) air filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.		Very rarely experienced on land; usually accompanied by widespread damage.		45-60	> 80	—	18.0	—	—

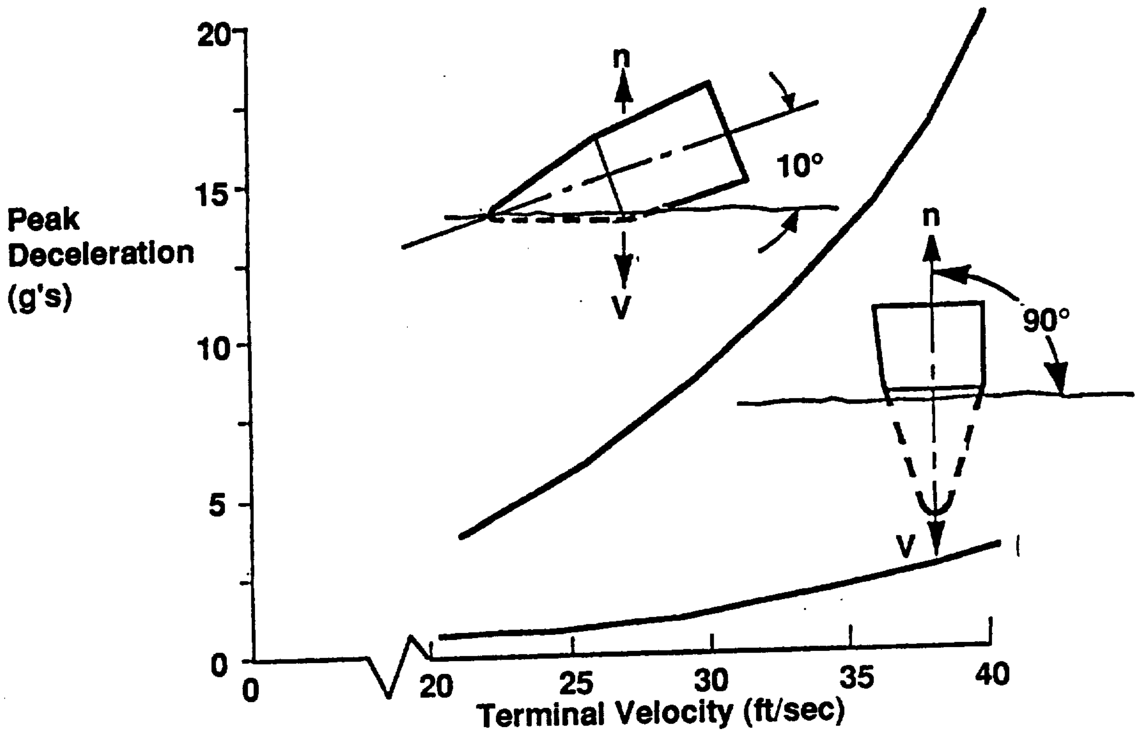


Figure 9.9.3-1 Effect of Water Entry Attitude

C-4

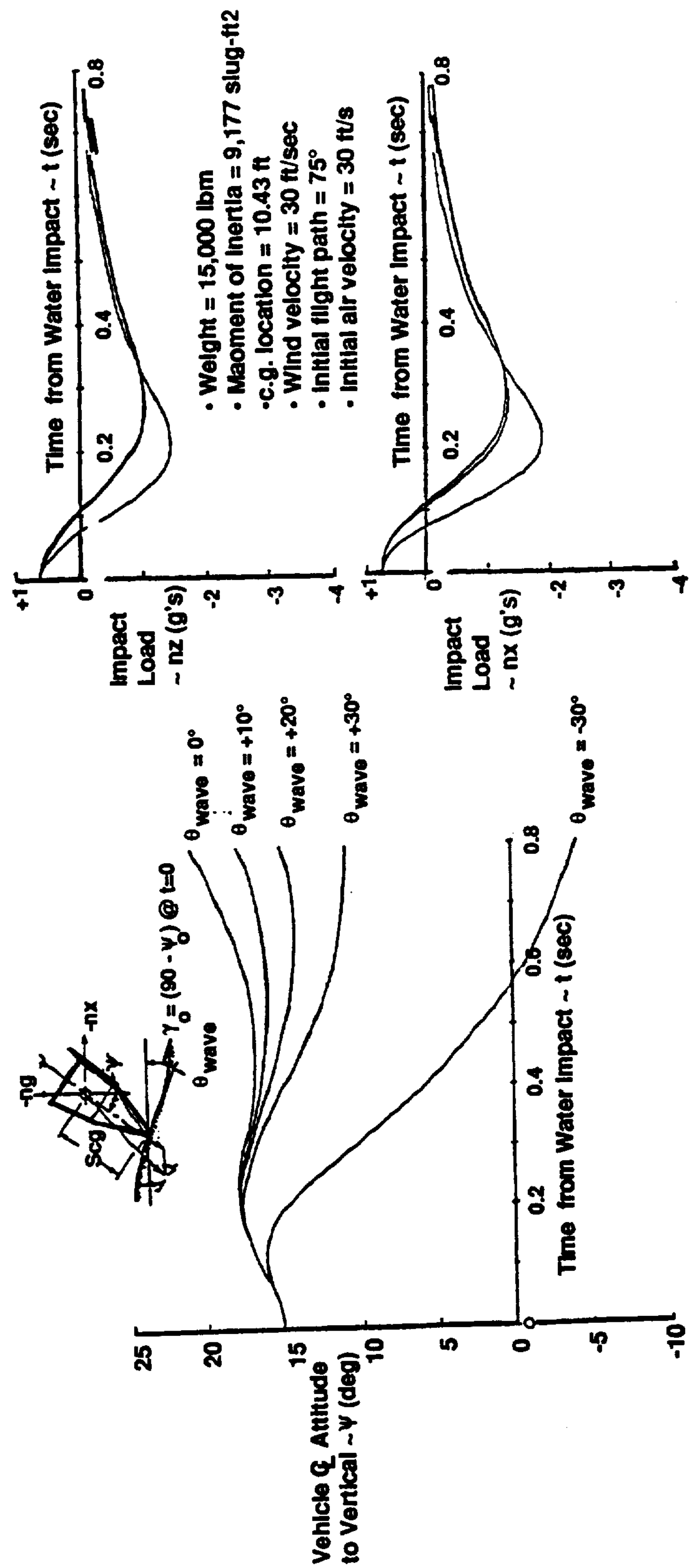


Figure 9.9.3-2 Effect of Water Slope at Impact

if the floatation characteristics are acceptable or if the addition of sea anchors or other stabilization devices is required.

9.9.4 Recovery/Transportability

After the vehicle has come to a stop, the personnel have egressed, and systems are shut down and safed, the process of recovering the reusable vehicle begins. Using a standard crane, the vehicle can be lifted to a transportation pallet using lift points located at the points where the parafoil risers attach. The use of the parafoil riser/control assembly may eliminate the requirement for any specialized GSE. Hard points (jack points in airplane parlance) located in the three landing gear cutouts are used to support the vehicle for transport and servicing.

The weight, envelope, and balance of the biconic PLS are consistent with standard C-5/C-17 transports for moving the vehicle to KSC (if the landing site is farther away than some site within the borders of KSC).

9.9.5 Preferred Concept Description

The recovery system trade began with a review of previous work in the area of space vehicle/component recovery systems. Among the most useful sources of information was the Advanced Recovery Systems (ARS) Study performed by Pioneer Aerospace under contract to NASA's Marshall Space Flight Center (References 24 and 25). The ARS study initially considered the best candidate recovery systems for a broad range of recoverable space payloads including manned reentry vehicles. The focus was later narrowed to concentrate on a Propulsion/Avionics (P/A) Module weighing up to 60 klb and requiring precise, soft, dry-land landing. The PLS study drew heavily upon the ARS study, where applicable, and made use of weight scaling relationships developed during the ARS study. The results of the Space Shuttle SRB Recovery System and B-1 Crew Capsule Escape System programs as well as the ACRV and other studies, were incorporated whenever possible.

Because space transportation systems continue to be weight driven and because recovery systems in particular are notably weight sensitive, weight was the focus of many of the basic trades. The selection of the parafoil over alternative gliding devices is a good example of a weight driven trade. Exotic devices such as semi rigid deployable wings were eliminated early in the study as not only too heavy but also too dependent on pre-developmental technology. An analysis of glide performance

versus weight was used to select the parafoil from among the candidate deployable gliding devices. The parafoil was found to offer not only the best glide performance but also the greatest performance per unit weight. This analysis was pivotal in the parafoil selection.

Cost has become the critical trade parameter for recent studies. In fact, some studies have expressed all other parameters in terms of cost to emphasize it's importance. For purposes of PLS recovery systems trades, cost was given equal value with weight, performance, and schedule considerations. Estimates of unit cost and DDT&E cost were provided for candidate recovery systems. Within the DDT&E category, the cost of man-rating large high glide devices was quantified.

The reliability requirements of man-rating large gliding devices (or any new recovery system for that matter) were the focus of considerable attention. A preliminary scaling relationship was devised attempting to express reliability of a large scale system based upon measured success rates of existing small systems. The value of this relationship was found primarily in illustrating the historical reliability trend resulting from the scaling-up of recovery system components (Table 9.9.5-1). Ultimately, large system reliability will be undetermined until such time as sufficient test data accumulates to establish statistically meaningful success rates. Preliminary cost and schedule estimates were provided for a testing program to adequately quantify reliability for a full scale high glide man carrying system (see Section 13 and 14).

The ARS study included an analysis of the effects of designing a parachute or parafoil system for single versus multiple uses. Experience gained in refurbishing and reusing the Space Shuttle SRB-DSS provided the basis for this analysis which focused on differences in system weight, component costs, and anticipated refurbishment costs. The weight and cost of reusable components was found to be only marginally greater than those of expendable components. The cost of facilities and manpower to refurbish, repair, repack and recertify those components is the driver. This cost is directly dependent on launch rate. Based on initial estimates of PLS launch rate, the preliminary decision was made to incorporate expendable fabric components in the recovery system. All interface hardware, stowage hardware, and control/sequencing components would be designed for reuse. This decision should be reviewed as launch rates are more precisely defined.

Table 9.9.5-1 *Parachute Reliability Data*

Reference System	Data Source	Drops	Equipment Malfunctions	Success Rate
Man Sized High Glide	US Army Golden Knights Team - 1 year	28,000	3	99.989%
Man Sized Ballistic	US Army Quartermaster School - 1 year	48,018	1	99.998%
Supply Equipment Ballistic Drops	US Army Quartermaster School - 1 year	13,718	17	99.876%

Several measures of performance were employed as discriminators for trades among different terminal descent systems (ballistic, low-glide, high-glide).

Deployability - The important issues associated with deployability are reefing systems technology requirements and resultant inflation loads management capability. While conventional parachute reefing systems technology is well established and reliable, large scale high glide reefing systems are largely developmental. The complexity of deploying semi-rigid wings was deemed prohibitive. On the other hand, the parafoil reefing system designed as a result of the ARS study and demonstrated during ARS Phase 2 provides an adequate technical basis for realistic selection of the parafoil terminal decelerator. In all cases, the flight velocity at which the descent system is deployed can have a significant impact on the reliability and the sizing of the primary decelerator. The PLS will incorporate a drogue chute (extracted by a pilot chute) for initial deceleration/stabilization before the primary decelerator is deployed.

Touchdown Velocity - The ability to control residual horizontal and vertical velocities and the resultant requirements for attenuation of these velocity components are major issues for a man-carrying system. Landing "g" loads must be carefully and reliably limited to those that are tolerable to crew members. One of the key trades performed during the PLS study was the land versus water operational selection. Control and attenuation of touchdown velocity is especially critical for land landing. The ability of the parafoil to perform a flared landing, attenuating both horizontal and vertical velocities, was an important factor in it's selection for the land landing system.

Wind Penetration - The ability to glide is essential for precise landing. The ability of such a system is exploited to counter wind drift, to achieve low level cross range correction, or both. The parafoil is the only terminal descent device to provide a credible horizontal velocity capability in the weight range of interest to PLS.

Touchdown Footprint - Touchdown footprint refers not only to the set of potential touchdown points determined by recovery system glide

potential and wind dispersions but also to the footprints of other components, including those routinely released during deployment and descent. The effect on touchdown point of potential failure modes must also be considered. The PLS recovery system candidates' footprint characteristics were found not to differ significantly from those of ARS Phase 1 baseline designs. Detailed definition of footprints and dispersions was deferred pending detailed PLS systems design.

The compatibility of the PLS program schedule with candidate recovery systems and their respective development programs was considered. The high glide system which has been baselined was found to have two potential schedule paths. The time required to develop the data necessary to man-rate a large scale parafoil is believed to be compatible with realistic PLS schedules. Alternatively, a cluster of conventional parachutes could be baselined with the high glide system developed in parallel and phased in during the operational life of the PLS system.

Technology gaps and areas requiring technology development were identified for each candidate system. The high glide recovery system of choice requires technology development in three significant areas. The means by which this development can be accomplished have been assessed.

Deployment/Reefing - The lack of a reliable and effective deployment management method/system has historically been the greatest single problem inhibiting application of high glide technology to large scale recovery systems. Major inroads have been made via the ARS Phase 2 demonstration test program which has validated the midspan method of reefing/deployment developed by Pioneer Aerospace. Parafoils of the size comparable to that required by the PLS recovery system have been successfully deployed with inflation loads held to acceptable levels (-3g's). Continued large scale airdrop testing is required to establish the reliability data base necessary for manned application. A series of high speed tests (probably off of a rocket) will also be required if the design is to include a supersonically deployed drogue.

Guidance and Control - The ARS Phase 2 airdrop and wind tunnel tests have established a control data base for large parafoils. Study efforts have been conducted by Boeing to evaluate requirements for guidance

of large parafoil systems. This work provides a suitable point of departure for design of a PLS recovery guidance and control system.

Flared Landing - Impact attenuation via a flared landing is a key feature of the high glide recovery system. Wind tunnel test data and preliminary airdrop results indicate that the flare will be effective and reliable. A fully flared landing of a full scale parafoil has yet to be demonstrated. Implementation of this maneuver via the GN&C suite will require significant development work.

A preliminary assessment of failure modes and effects was undertaken as part of the reliability analysis. Recovery system failure modes analysis led to the decision to incorporate fully redundant components for all major recovery system hardware (drogue and parafoil). Actual airdrop test space position data was incorporated in the analysis of pad abort scenarios.

The performance, cost and safety advantages of the high glide recovery system provide a flexibility and reliability otherwise unachievable in a cost effective manner. While there are significant technology advancement issues to be resolved, the value of the system justifies the necessary development work. A vehicle exists to perform the necessary work in the form of the MSFC ARS Program.

For impact attenuation, the baseline design includes two primary stroking struts with skids for the primary impact attenuation and a small castoring wheel (to prevent a tip-over) attached to a trailing arm strut located in the pointed end of the vehicle (aft end on landing). Large skids/pads for low surface loading are part of the exterior vehicle skin and form the cover/door to the small well in the fuselage housing a gas cartridge deployed gas filled strut. Retrorockets were eliminated because of the extra on-board ordnance required (operational/safety issue). Airbags were complex for the biconic shape and a high center of gravity requires a widely spaced footprint. With the exception of the gas generating cartridges used for deployment, all components are fully reusable. An equipment list for the recovery systems is shown as Table 9.9.5-2.

9.10 DRM Unique Hardware

Most of the traffic envisioned for PLS involves transportation to and from the SSF (DRM 1). As a result, most of the design definition has focused on this crew rotation mission. If other missions are considered for a PLS, there are some changes that

Table 9.9.5-2 Recovery and Auxiliary Equipment List

Wbs	Item	Crew Rotation Qty	Weight (Lb)		Description
	Parachute System			1725	
	Drogue Chutes	1	290		Terminal Velocity=160 Fps, 53.0 Ft Diameter, Mortar-deployed
	Backup Drogue Chute	1	290		Fully Redundant System
	Main Chute - Hi-glide	1	444		Full-open Vv = 22.0 Fps, 7000 Sf Wing Area
	Backup Chutes - Hi-glide	1	444		Fully Redundant System
	Parachute Cntrl Spindle, Motors	2	100		For Hi-glide Control Lines -- Redundant System
	Parachute Supt/Instl		158		
	Landing System			606	
	Nose Landing Gear	1	108		Deployed Landing Gear With Skid
	Rolling Gear	2	431		
	Flotation Collar Airbags	4	12		For Righting In Abort Water Landing
	Landing Gear Supt/Instl		55		
	Separation			190	
	Parachute Covers Separation	2	40		Clamped Cover With Spring Deployment
	Fwd Fairing Separation	1	60		Zip-joint With Bolt-on Flange
	OMS Module Separation	6	90		Explosive Bolt Installation With Nutcatchers
1.1.5 1.1.16	**Other - Recovery & Auxiliary**			**2522**	
	Launch Vehicle Separation	6		90	Explosive Bolt Installation With Nutcatchers
	OMS Pod Separation	6		60	Explosive Bolt Installation With Nutcatchers
1.6.16	**Separation - OMS Module**			**150**	Explosive bolt Installation
	Separation - Launch Escape Sys	3		**32**	

would be required for the hardware and operations. In general, the majority of equipment would remain the same; the differences are outlined in the following sections. Note that DRM 5 is discussed before DRM 4; there are many similarities between these missions and DRM 5 (Satellite Servicing) was a higher priority in the mission model.

9.10.1 DRM 2 Hardware

Space Station Standby, or DRM 2, would utilize the PLS in a long duration, primarily dormant manner. In a scenario similar to Apollo/Skylab or Soyuz/Salyut/Mir fights, a space station crew would ascend and dock in a PLS, secure the PLS in a dormant mode, and reactivate the vehicle when it's time to depart (180 days nominally, although it would be available sooner in an emergency). This technique would provide for an emergency return capability for the SSF crew at all times, similar in concept to the ACRV program currently under study.

Two design "drivers" can be derived from this mission scenario. The first set of requirements results from the long duration in space (180 days maximum versus 7 days maximum required for other missions). A second set of requirements is incurred by the dormant nature of the vehicle while docked. The reliability of a reentry after a period of quiescence is an issue not common to other PLS missions. Duration and dormancy tend to imply similar requirements: high reliability; fault tolerance; and environmental robustness to name a few. Changes to specific subsystems are described below.

EPS - Fuel cells are not a good choice for this mission. The volume of reactants required for a long duration operation may be prohibited (as well as the problems of managing boil-off of cryogenic reactants). There are also issues associated with restarting a fuel cell after a period of dormancy that have not been resolved with current fuel cell technology. Battery systems, perhaps with a solar cell recharge, could be used, but the weight and volume required may not be acceptable. SSF power could, in theory be used for the low power levels required by the PLS during quiescence (complete shutdown being unlikely). At this time, however, it appears unlikely that the SSF could spare the power for a PLS, nor is it likely (for safety reasons) that this extra interface would be accepted by the SSF program. The most likely EPS would involve internal batteries for descent and external expendable

batteries (integrated into the radiator/OMS module) with a small solar array for on-orbit operations.

ECLSS - Physical isolation of the SSF and PLS atmospheres are probably desirable for safety (safe haven) and system sizing (SSF ECLSS not sized to support PLS volume). In the absence of personnel on board the PLS, the current ECLSS hardware could operate periodically at a low power level sufficient to maintain thermal control. Sealing the LiOH cannisters against gradual degradation would be required. As for the EPS, the SSF will probably not allow the PLS to use the station's TCS or ECLSS for safety and complexity reasons. Further study would be required to ascertain if the radiated heat from the PLS (or its radiator) or the screening/shadowing of a docked PLS would adversely affect the station.

Propulsion - Long duration missions would alter the selection of propellants to ensure stability and minimize boil-off. As the only cryogen currently used, the LOX is currently carried externally in the expendable module, and could be changed (say, to hydrogen peroxide) with a minimum of change to the rest of the PLS vehicle.

Avionics - Long term space exposure increases the likelihood for "upsets" or radiation induced failures. Redundancy and robustness (fault tolerance) beyond what is required for the other missions may be necessary.

General - Long term exposure to radiation, hard vacuum, thermal cycling/distortion, micrometeorites, and atomic oxygen can have a profound negative impact on many materials. At this stage, it is not known if the selections that have made would be the same for a "short term" and long duration PLS. System reliability generally decreases with time and must be accounted for to ensure a safe return. In particular, a deconditioned crew will not be able to perform any piloting functions - a fully autonomous system is a requirement, not just a goal, and the avionics systems must be sufficiently reliable to perform these tasks after "waking up".

9.10.2 DRM 3 Hardware

Manned Space Rescue (DRM 3) is the mission with the least definition. How "rescue" is interpreted will significantly determine the required hardware and operations. It was understood that a <u>ground-based</u> rescue capability was to be explored. Space basing of an autonomous, dormant rescue PLS (such as defined by DRM 2) should also be considered as an alternative.

A commitment to space rescue capability implies several points:

1) A PLS vehicle in the ground processing flow must have the capability of rapidly being reassigned/reconfigured, or,

2) An extra PLS vehicle is required in the fleet, along with its attendant storage facility

3) PLS may require features that enable a "cold start" with a high degree of confidence, as no time is available for extensive test and checkout

4) Additional training procedures and facilities must be accounted for

5) A launch vehicle, launch site, propellants, etc. must be available in a short period of time.

The last point is very crucial. The PLS design could be made to support space rescue relatively easily compared to the commitment required to support a rapid booster launch.

Postulated rescue scenarios vary significantly and will drive the hardware/operations requirements. For example, on one extreme: a pressure leak on an orbiting spacecraft forces the crew into pressure suits or a safe haven, a rescue must be effected in a few hours. Or, a gradual system degradation or launch vehicle stand down requires an unscheduled return of an orbiting crew; time to respond may be weeks from initiation of the "rescue" mission. No attempt was made to determine where in this spectrum of scenarios the "real" requirements originate.

As broadly stated, space rescue could conceivably involve a PLS rendezvous with one of the following spacecraft:

- SSF
- STS Orbiter
- another PLS
- Mir
- NASP? Hermes? HOPE? Sanger/HORUS? HOTOL? etc.

There are two types of personnel transfers that might transpire in a rescue operation. Hard docking would require the PLS to dock, equalize atmospheres, transfer crew members onto the PLS in a shirt sleeve environment, and return to Earth. Another method would use an extravehicular transfer where personnel are "carried" in pressure suits (even partial pressure suits are adequate for short durations) between an airlock on the afflicted vehicle and the PLS airlock.

Specific hardware requirements for rescue DRMs then might include any of the following equipment:

- Adaptive guidance algorithms with appropriate processors to enable rapid on-board retargeting and rendezvous
- Seats/restraints in sufficient quantity for the returning personnel.
- Docking ring or device compatible with the spacecraft to be rescued. The PLS design features a planar interface ring onto which a variety of adapter/docking devices could be attached.
- Pressure garments or enclosures (such as the personal rescue enclosure, or rescue ball, proposed for STS) for extravehicular transfer.
- Airlock for extravehicular transfer or rescue operations, or capability for cabin depressurization/repressurization (not recommended for safety issues related to hatch closure).
- Medical equipment for stabilizing rescued personnel with physical trauma.
- Repair equipment such as cutters, patches, and welding equipment as may be required to extricate personnel or perform time critical salvage repairs.

Again, although not strictly a PLS vehicle requirement, a launch vehicle/site with sufficient performance to the desired inclination/altitude is required.

9.10.3 DRM 5 Hardware

Satellite Servicing (DRM 5) comprises the second largest number of potential PLS missions. Given scenarios call for two pilot-astronauts and two mission specialists to work on some undefined orbital object for up to 7 days. Two mission types, a high inclination (57^{o} to 99^{o}) 169 nmi orbit and a low inclination (28.5^{o} to 57^{o}) 320 nmi orbit were considered, the main difference being the amount of OMS propellant. Two rendezvous maneuvers are planned (with two missed attempts), and EVA capability is required.

Changes to the basic PLS subsystems are as follows:

Accommodations - removal of extra seats, addition of waste management system/hygiene station module, and addition of a galley module with extra food storage

EPS - additional fuel cell reactants and possibly the addition of a deployable solar array (depending on required power levels).

Propulsion - additional OMS propellants for high altitude missions, additional cold gas for additional rendezvous/proximity operations

ECLSS - replenishment/make-up gases associated with EVA.

Other equipment will be required depending on the envisioned service function to be performed by the PLS. "Servicing" could mean LRU replacement, hardware upgrades, structural/TPS repair, remote inspection, or propellant refill. Remote inspection implies travel by a suited astronaut away from the PLS to another spacecraft using a Manned Maneuvering Unit (MMU). The MMU is a large, expensive device that would not fit through the PLS hatch for storage, and is probably too valuable to throw away at the end of the mission. Therefore, it was decided that this servicing function was not likely to be performed by a PLS. Similarly, propellant refill, which would involve some form of tank "farm" transferring fluids under PLS supervision to a spacecraft, was considered an unlikely PLS mission for safety reasons and was dropped from further consideration. The other servicing functions are cross referenced to probable equipment required as Table 9.10.3-1.

Table 9.10.3-1 Satellite Servicing Hardware Requirements

Service Function	Grapple Arm	RMS	MMU	EMU	Airlock	Tank Farm	Spares Module
LRU Replacement / Upgrade Hardware	X	X		X	X		X
Propellant Refill	X	X				X	
Remote Inspection			X	X	X		

The physical size and weight of this servicing hardware may not be consistent with the safe return of the baseline PLS design. If all equipment is to be recovered with the PLS, the vehicle must be scaled up, resulting in a major configuration penalty that will subsequently affect the launch vehicle, ground operations, and ultimately LCC. Partial expendability, where the bulky servicing items are thrown away at deorbit and smaller high value items return with the PLS, results in some cost savings, but still adversely affects the vehicle weight and balance. Full expendability would represent the minimum configuration penalty and would allow for a variety of "custom" servicing arrangements to be attached. As an alternative to the expense of throwing away this hardware, the "expendable" servicing hardware could be spaced based, possibly stored at SSF. If the satellite to be repaired is in a substantially different orbit however, the OMS energy requirements may be prohibitive. Six options for configuration arrangements including varying degrees of expendability are shown on Figure 9.10.3-1. A mass comparison, shown as Table 9.10.3-2, describes the weight and balance impact of servicing hardware options.

9.10.4 DRM 4 Hardware

Orbital Sortie (DRM 4) missions are generally described as scientific observation missions to LEO. As given, a crew of 2 pilot-astronauts and 2 mission specialists will spend up to 7 days making observations which may include EVAs. Specific hardware changes are similar to those for DRM 5 and include:

Accommodations - remove extra seats, install modular waste management/hygiene equipment and a galley/food storage.

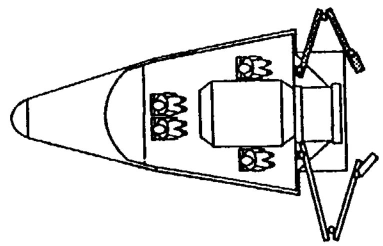
EPS - additional reactants required, supplemental power systems, such as a deployable solar array may be required for special scientific equipment.

EVA - addition of an airlock, ECLSS replenishment gases, and Extravehicular Maneuvering Units (EMUs or space suits).

ECLSS - additional LiOH cannisters

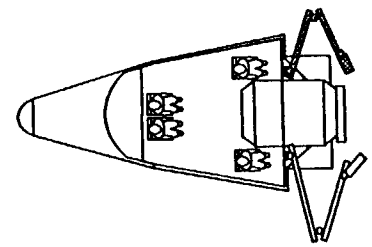
Scientific Hardware - camera mounts or special cooling equipment may be required.

Option 1



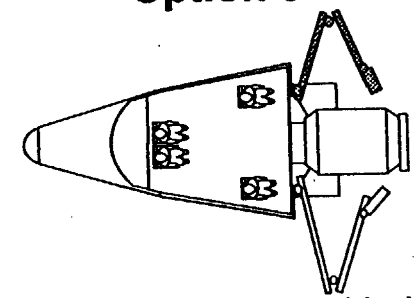
- Internal removable airlock (aft bulkhead removal)
- Removable RMS, grapple arm, and spares module on base bulkhead
  - 15 ft RMS, 12 ft grapple
- +15% Volume increase (5% dimension increase)

Option 2



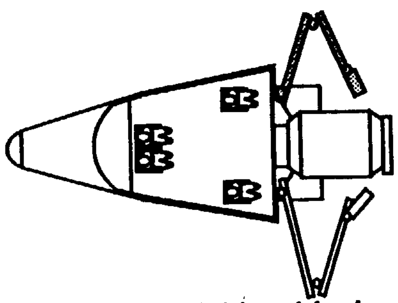
- Protruding, removable airlock (replace with aft bulkhead, tunnel)
- Removable RMS, grapple arm, and spares module on base bulkhead
  - 18 ft RMS, 15 ft grapple
- +7% Volume increase (2% dimension increase)

Option 3



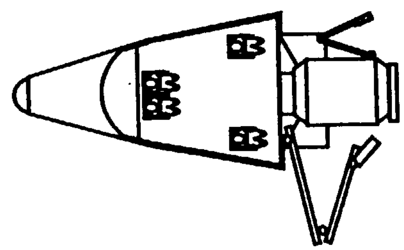
- External retrievable airlock (retrieved in LEO)
- Removable RMS, grapple arm, and spares module on base bulkhead
  - 22 ft RMS, 19 ft grapple

Option 4



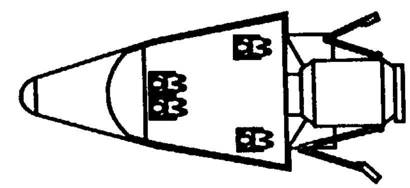
- Expendable airlock and spares module
- Removable RMS and grapple arm on base bulkhead
  - 22 ft RMS, 19 ft grapple

Option 5



- Expendable airlock with grapple arm mount
- Expendable grapple arm and spares module
- Removable base-mounted RMS
  - 22 ft RMS, 12 ft grapple

Option 6



- Expendable airlock with grapple arm and RMS mounts
- Expendable RMS, grapple arm, and spares module
  - 15 ft RMS, 12 ft grapple

Figure 9.10.3-1 Satellite Servicing Hardware Arrangement Options

Table 9.10.3-2 *Weight and Balance Comparison of Satellite Servicing Options*

	Crew Rotation XCG	Crew Rotation Mass - lb	Option 1 XCG	Option 1 Mass - lb	Option 2 XCG	Option 2 Mass - lb	Option 3 XCG	Option 3 Mass - lb	Option 4 XCG	Option 4 Mass - lb	Option 5 XCG	Option 5 Mass - lb	Option 6 XCG	Option 6 Mass - lb
CREW MODULE DRY WEIGHT	160	19234	160	19234	160	19234	160	19234	160	19234	160	19234	160	19234
Satellite Service Dry Weight Changes	0	0	208	4648	230	4053	246	4083	246	4083	252	3988	259	3866
External Shell Struct/TPS Mods				+730		+260								
Pressure shell struct mods				+120		-50								
Personnel provisions deletions				-683		-683		-683		-683		-683		-683
Personnel Provisions additions				+678		+678		+678		+678		+678		+678
Airlock Module				+700		+700		+770		+770		+820		+870
Spares Module, Tools, Support				+200		+200		+200		+200		+200		+200
EMU's				+536		+536		+536		+536		+536		+536
RMS Workstation				+100		+100		+100		+100		+100		+100
RMS				+450		+516		+606		+606		+606		+450
Grapple Arm				+300		+356		+432		+432		+300		+300
EPS Tankage				+280		+280		+280		+280		+280		+280
RCS Propellant Tankage/plumbing				+278		+278		+278		+278		+278		+278
RCS Pressurant Tankage / Plumbing				+78		+78		+78		+78		+78		+78
Prox ops tankage / plumbing				+275		+275		+275		+275		+275		+275
Weight Growth Margin				+606		+529		+533		+533		+520		+504
NON-CARGO ITEMS	179	3530	199	2019	199	2003	199	2003	199	2003	199	2001	199	1998
NON-PROPELLANT CONSUMABLES	103	694	128	952	139	952	156	952	156	952	156	952	156	952
RCS PROPELLANT - NOMINAL	242	557	242	1330	242	1303	242	1305	242	1305	242	1300	242	1295
OMS / RADIATOR MODULE	9	3982	9	3982	9	3982	9	3982	9	3982	9	3982	9	3982
OMS PROPELLANTS	0	3361	0	4539	0	4449	0	4454	0	4454	0	4440	0	4421
ON-ORBIT GROSS WEIGHT	126	31359	134	36704	136	35976	138	36013	138	36013	139	35897	139	35748
Reentry Mass	162	23313	171	26488	174	25873	173	25015	171	24460	169	23957	167	23254
Landing Mass	159	22328	168	25485	171	24874	170	24019	168	23467	166	22967	164	22267

(shaded) Dropped Prior to Reentry

9.11 Reusability/Expendability Trades

Space qualified, man rated hardware is expensive. The cost of labor and facilities associated with refurbishing hardware is also significant. There is a balance where expendability and reusability are both found in a successful design.

As shown, the centerpiece of the PLS, the manned, pressurized crew cab, is to be designed for a life of 50 flights. Certain subsystems were considered for expendability. There are several reasons why some subsystems might be expendable:

- Safety - some systems, such as propellant tanks, should be physically isolated from the crew to protect against toxic leaks or ruptures where shrapnel could damage other critical systems.

- Volumetric Efficiency - packaging certain bulky or oddly shaped systems can adversely size the entire vehicle, resulting in significant weight growth.

- Ground Processing - improved access during maintenance or parallel processing may be best accomplished by a separate hardware set; if the item s jettisonable when expended, this is particularly true. Also, hazardous materials (such as propellants) can be isolated with sealed diaphragms and handled more easily than if a cycling valve were the only seal.

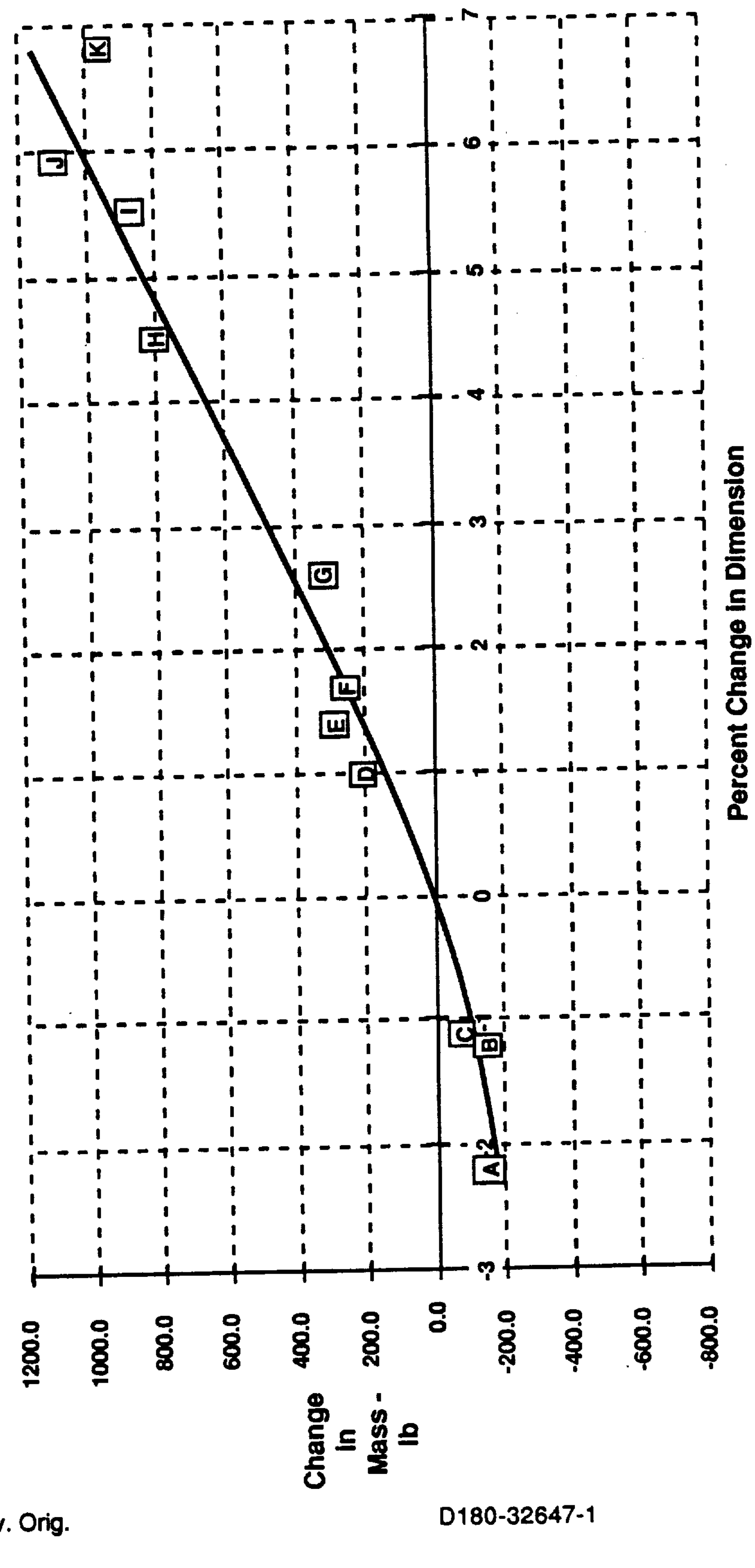
- Cost - with a limited number of total flights, hardware qualified to be used once and replaced can be less expensive than a reusable design.

- Growth - some systems, particularly consumables, will grow in volume with an expanded mission profile. Locating this equipment externally where is is expendable is one design technique that allows system growth without a major scaling of the rest of the vehicle.

In the case of the PLS, several items were considered for expendability: OMS (tankage and engines), RCS (tankage and thrusters), Proximity Operations System tankage, radiators, fuel cells (cells and tankage), and parachutes. The cost comparisons between reusable and expendable hardware are covered in Section 14. In most cases, expendability meant that the subsystem was located external to the biconic shape. The assumption was that the reusable hardware must be physically protected from the reentry heating, probably within the TPS or under a blanket on the lee side (base area) of the vehicle. The point of departure (scale factor = 1.0) features an external OMS, external RCS, external Proximity Operations System tankage, internal fuel cells and tankage, external radiator, and internal parachutes. Keeping the other internal volume a constant, the linear scale factor was adjusted to accommodate the internalization of plausible hardware options. The weight and volume impact of carrying these items internally or externally is shown as Figure 9.11-1 (tabular data is listed as Table 9.11-1). As one would expect, internalizing the additional systems leads to a vehicle scale-up. For reference, in the case of the 10 person biconic, a scale-up of 10% would not significantly affect the launch vehicle or transportability constraints.

If a system is to be expendable, it is designed to different criteria and thus will cost a different amount than reusable hardware. In particular, the propulsion system hardware would have very different attributes. Table 9.11-2 describes the typical differences between expendable and reusable propulsion hardware .

From an operations standpoint, location of the propellant tankage external to the biconic shape is probably desirable. Access and/or fueling operations would be simpler. Figure 9.11-2 consists of engineering drawings that were used to explore options for internalization of propulsion hardware (in this case based on the POD which featured NTO/MMH, but the trends are the same as for the final system). Table 9.11-3 lists the mass changes associated with these propulsion expendability options. Note that while it is possible to protect the OMS hardware for reuse, the complexity of a cover was deemed inconsistent with flight safety as a failure to seal the cover would be a flight critical event.



A: Fuel Cells / Tanks External
B: Parachutes External
C: Fuel Cells External
D: RCS Tanks Internal

E: OMS Engines Internal
F: Prox Ops Tanks Internal
G: RCS & Prox Ops Tanks Internal
H: OMS Tanks Internal

I: OMS & RCS Tanks Internal
J: OMS Tanks / Engines Internal
K: OMS, RCS, PO Tanks Internal

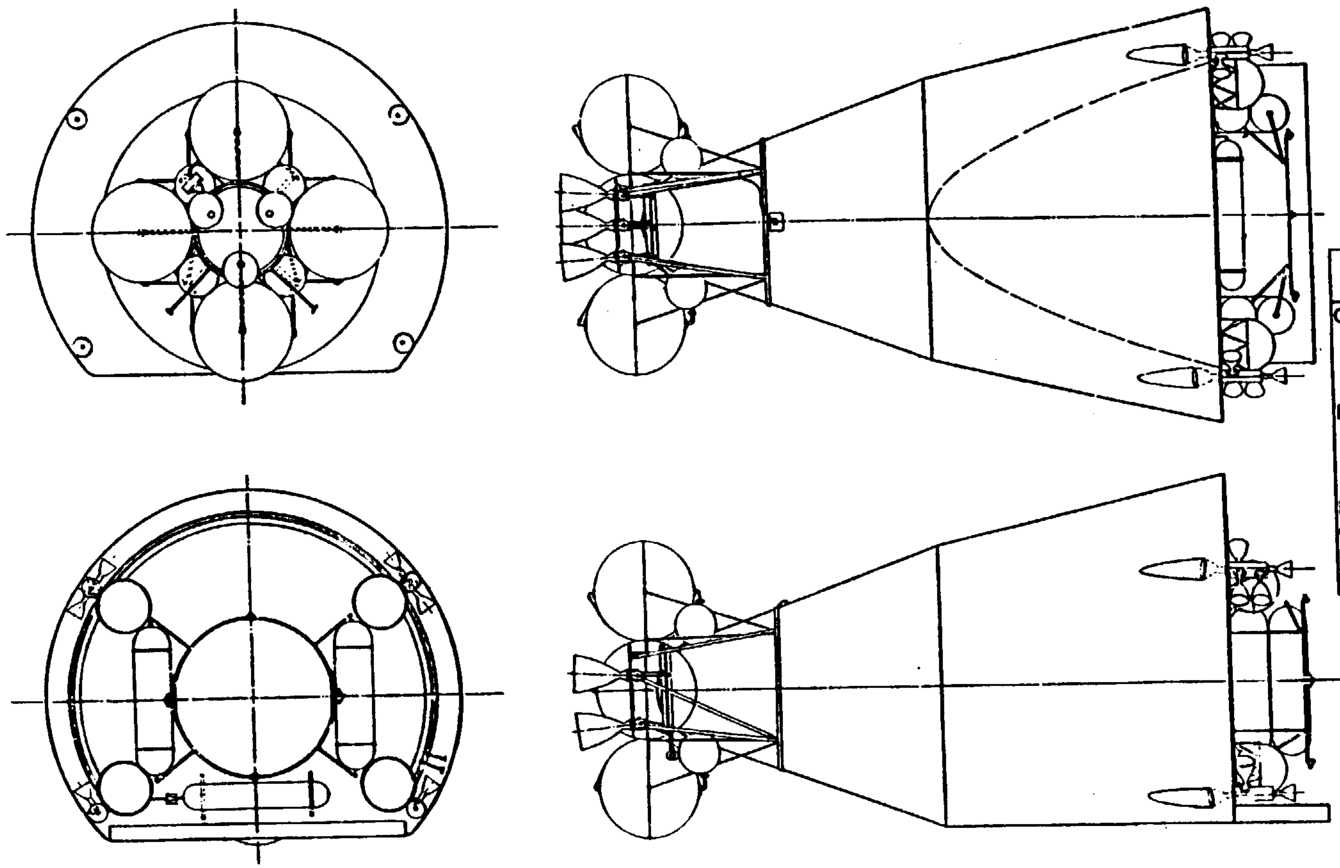
Figure 9.11-1 Structural/TPS Variation With Vehicle Scale Factor

Table 9.11-1 Mass Impact of Scaled Options

	Modification Location	Modification	Dimension Change (5)	Structural / TPS Mass change: External shell TPS	Structural / TPS Mass change: Fwd Nose Doors	Structural / TPS Mass change: Aft Bulkhead	Structural / TPS Mass change: Cabin Bulkheads	Parachute/ Landing Gear	Total Change
A	Comb	Fuel Cells & tanks out	-2.2	-134.2	0.0	0.0	0.0	-17.2	-151.4
B	Aft	Parachutes out	-1.2	-73.2	0.0	0.0	-55.2	-16.4	-144.8
C	Fwd	Fuel Cells out	-1.1	-67.1	0.0	0.0	0.0	-8.6	-75.7
REF	Ref	Reference	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D	Aft	RCS Tanks in	1.0	61.0	0.0	126.5	0.0	24.0	211.5
E	Fwd	OMS Engines in	1.4	85.4	172.5	0.0	0.0	33.0	290.9
F	Aft	PO Tanks in	1.7	103.7	0.0	126.5	0.0	29.5	259.7
G	Aft	RCS & PO tanks in	2.6	158.6	0.0	126.5	0.0	36.5	321.6
H	Aft	OMS tanks in	4.5	274.5	0.0	126.5	310.5	91.1	802.6
I	Aft	OMS & RCS tanks in	5.5	335.5	0.0	126.5	310.5	98.9	871.4
J	Comb	OMS tanks, engines in	5.9	359.9	172.5	126.5	310.5	124.1	1093.5
K	Aft	OMS, RCS, PO tanks in	6.8	414.8	0.0	126.5	310.5	109.0	960.8

Table 9.11-2 Differences Between Reusable and Expendable Propulsion Hardware

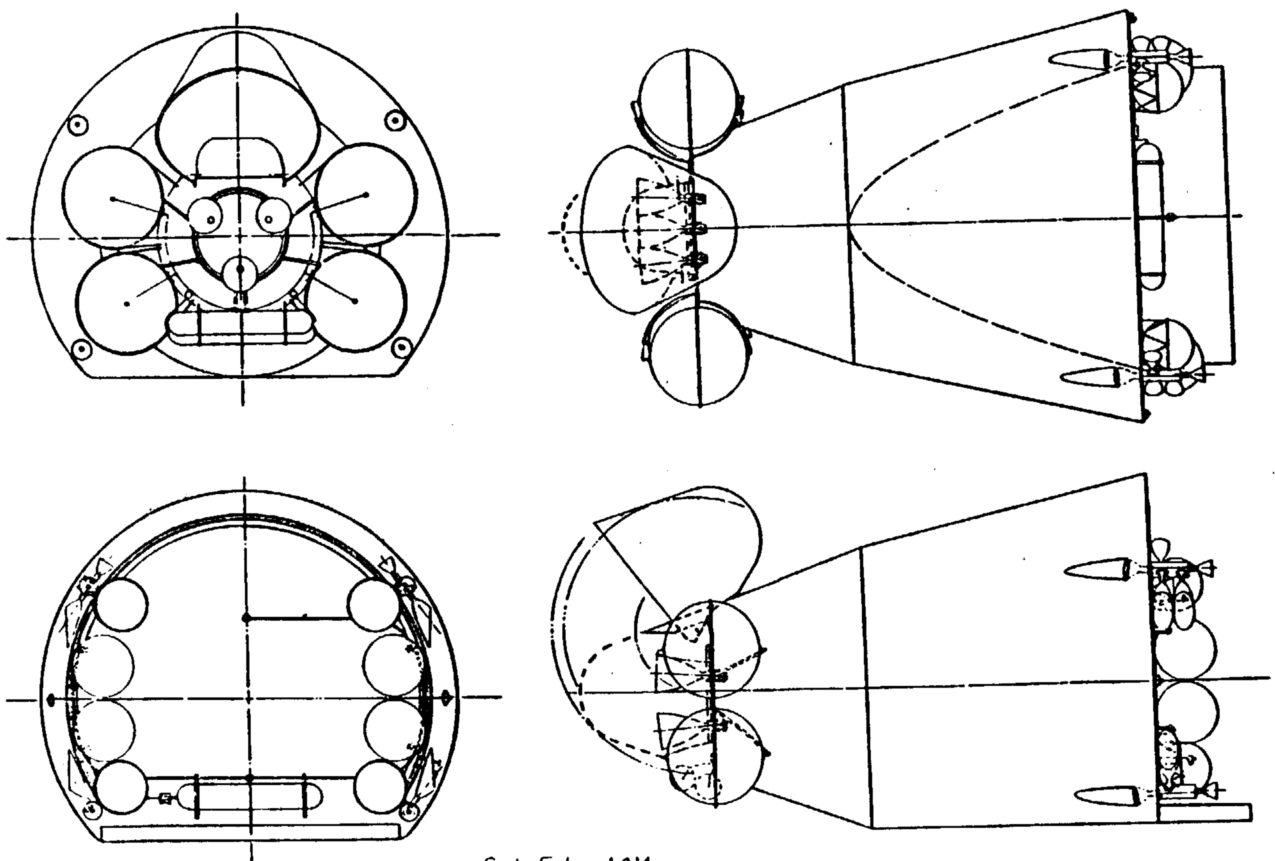
	EXPENDABLE	FULLY REUSABLE
Number of units	~250 shipsets	~10 shipsets
Cycle life	<20	>200
Equipment lifetime	3 days non-operational	140 days non-operational
	20 minute operational	7 hours operational
Design margin	<5 %	> 20 %
Durability	one flight	50 missions
Technical maturity	SOA	demonstrated by 1992
System fluid leaks	up to 1% / day if safe	none: 1E-6 scc/s He
Size considerations	bigger, bulkier, heavier	small, compact, maintainable
Maintenance	one flight	similar to Shuttle
Health monitoring	safety critical only	safety + maintenance critical
Test env.: pressure	1E-6 to 16 psia	1E-12 to 19 psia
temperature	45 to 100°F	-65 to 140°F
shock	10 G's at 41 Hz	20 G's at 41 Hz
vibration	8.0 g-rms	12.0 g-rms
cleanliness	300μ particles max	10μ particles max
Avionics capability	minimal	moderate
Storage/ ground depot	none	many
Material compatibility	not an issue	M & P effort required for 10 year life
Nozzle	Phenolic ablator	Regen. cooled Inconel or Hastelloy
Valves	Squibs, single seats	No squibs, dual seats
High pressure gas bottles	Glass overwrap	Kevlar or Gr/epoxy overwrap
Propellant tanks	St. steel with metal diaphram	Titanium with elastomeric or s. tension
Instrumentation	±5%	±1%



Propulsion Element	Reusable	Internal
OMS		
Engines		
Tankage		
RCS		
Thrusters	●	
Tankage	●/O	
Proximity Operations		
Thrusters		
Tankage		

Option 1,25

Figure 9.11-2 Propulsion Integration Studies (Page 1 of 10)



Propulsion Element	Reusable	Internal
OMS		
Engines	●	●
Tankage		
RCS		
Thrusters	●	
Tankage	●/O	
Proximity Operations		
Thrusters	●	
Tankage	●	

Option 7,9

Scale Factor •1.014

Figure 9.11-2 Propulsion Integration Studies (Page 2 of 10)

Propulsion Element	Reusable	Internal
OMS		
Engines	●	●
Tankage		
RCS		
Thrusters	●	
Tankage	●/O	
Proximity Operations		
Thrusters		
Tankage		

Option 27,29

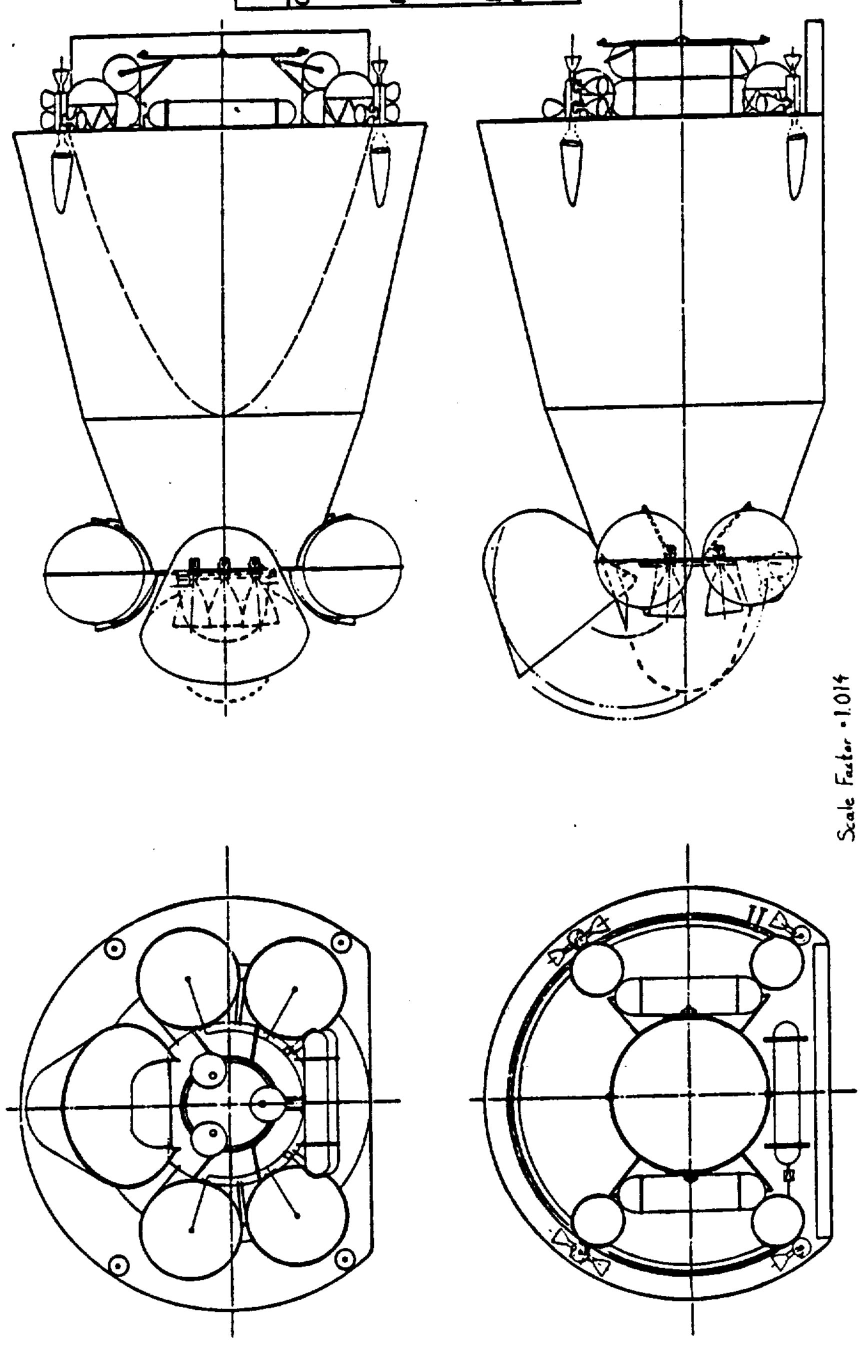
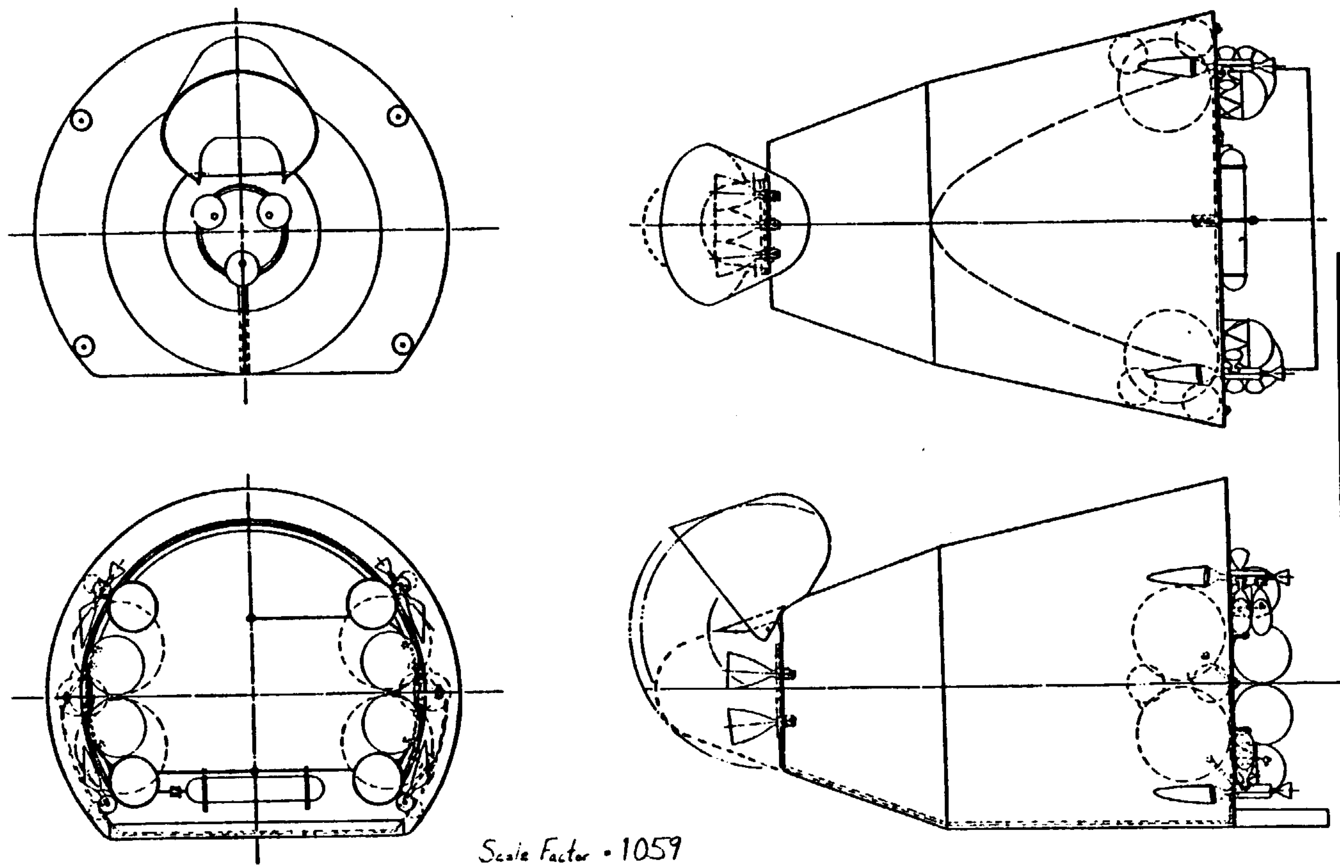


Figure 9.11-2 Propulsion Integration Studies (Page 3 of 10)



Propulsion Element	Reusable	Internal
OMS		
Engines	●	●
Tankage	●	●
RCS		
Thrusters	●	
Tankage	●/O	●
Proximity Operations		
Thrusters	●	
Tankage	●	

Option 11

Figure 9.11-2 Propulsion Integration Studies (Page 4 of 10)

Propulsion Element	Reusable	Internal
OMS		
Engines		
Tankage		
RCS		
Thrusters	●	
Tankage	●/O	●
Proximity Operations		
Thrusters		
Tankage		

Option 3

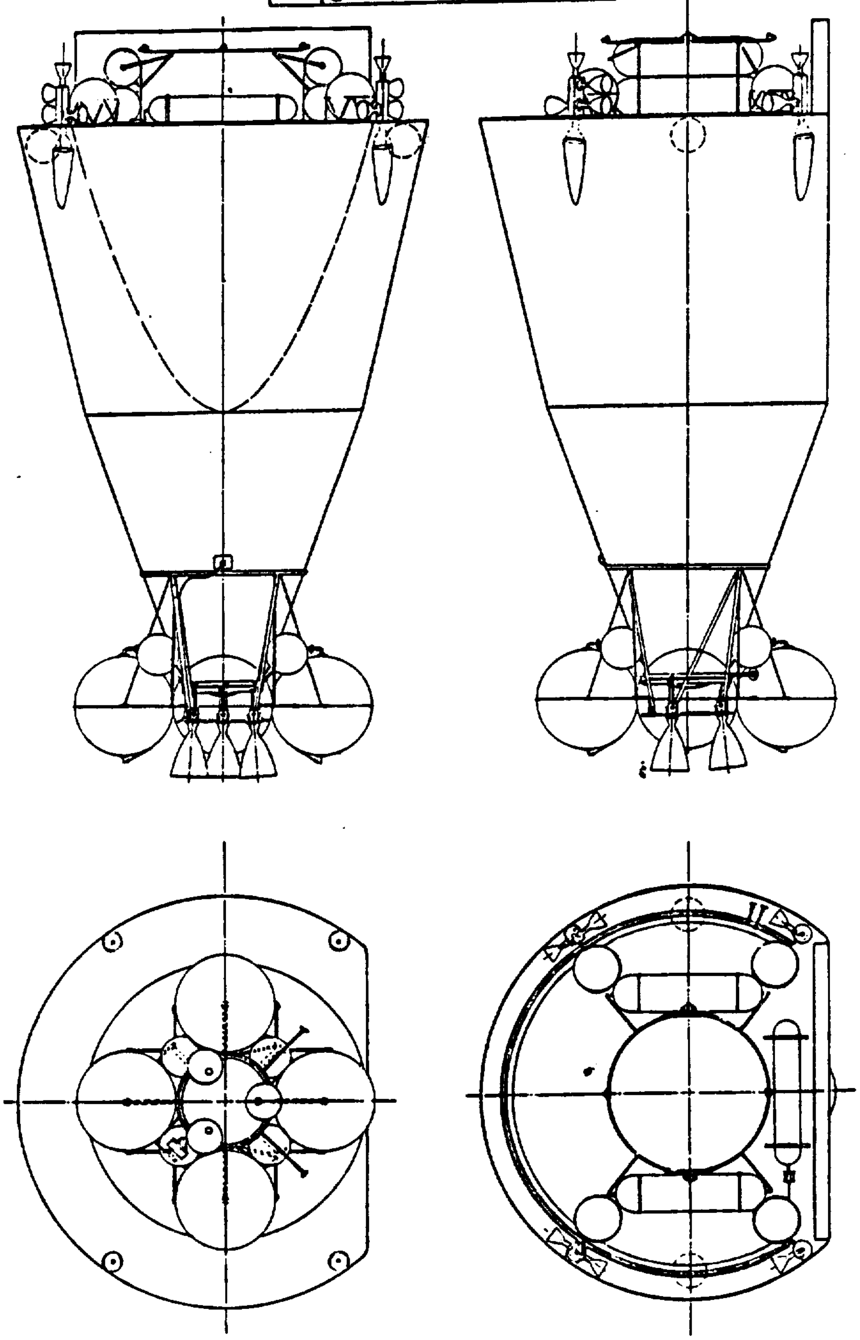
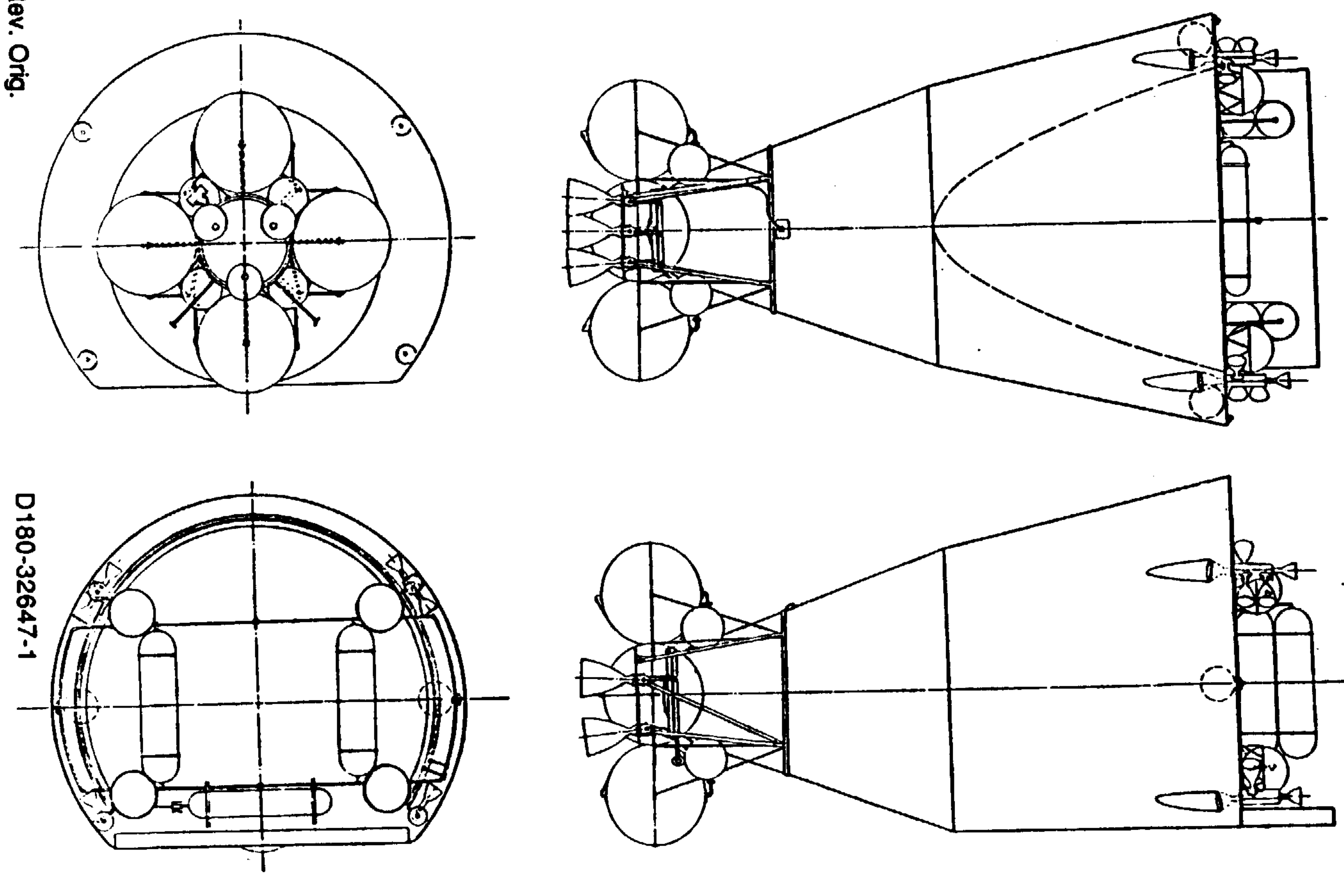


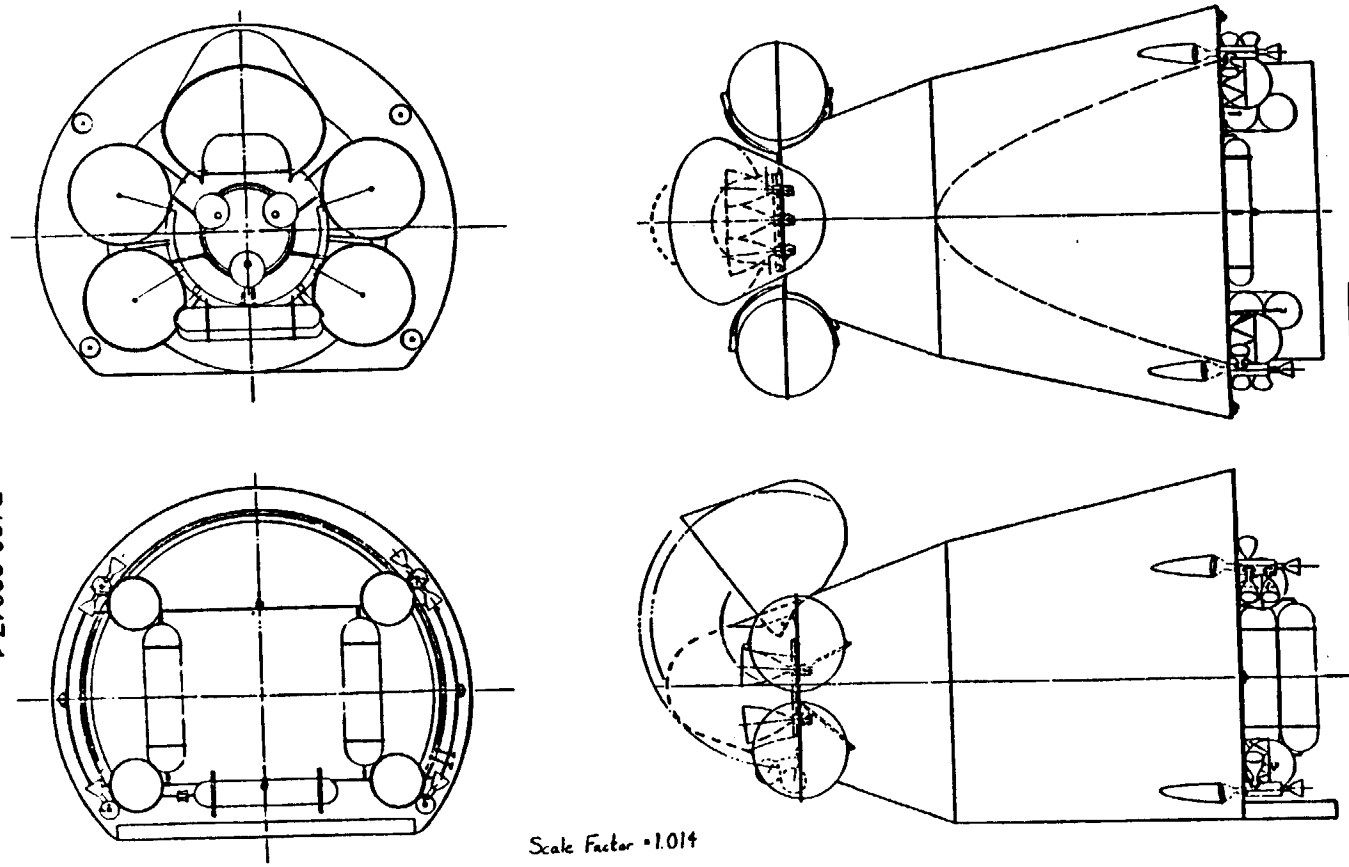
Figure 9.11-2 Propulsion Integration Studies (Page 5 of 10)



Propulsion Element	Reusable	Internal
OMS		
Engines		
Tankage		
RCS		
Thrusters	●	
Tankage	●/O	●
Proximity Operations		
Thrusters	●	
Tankage		

Option 15

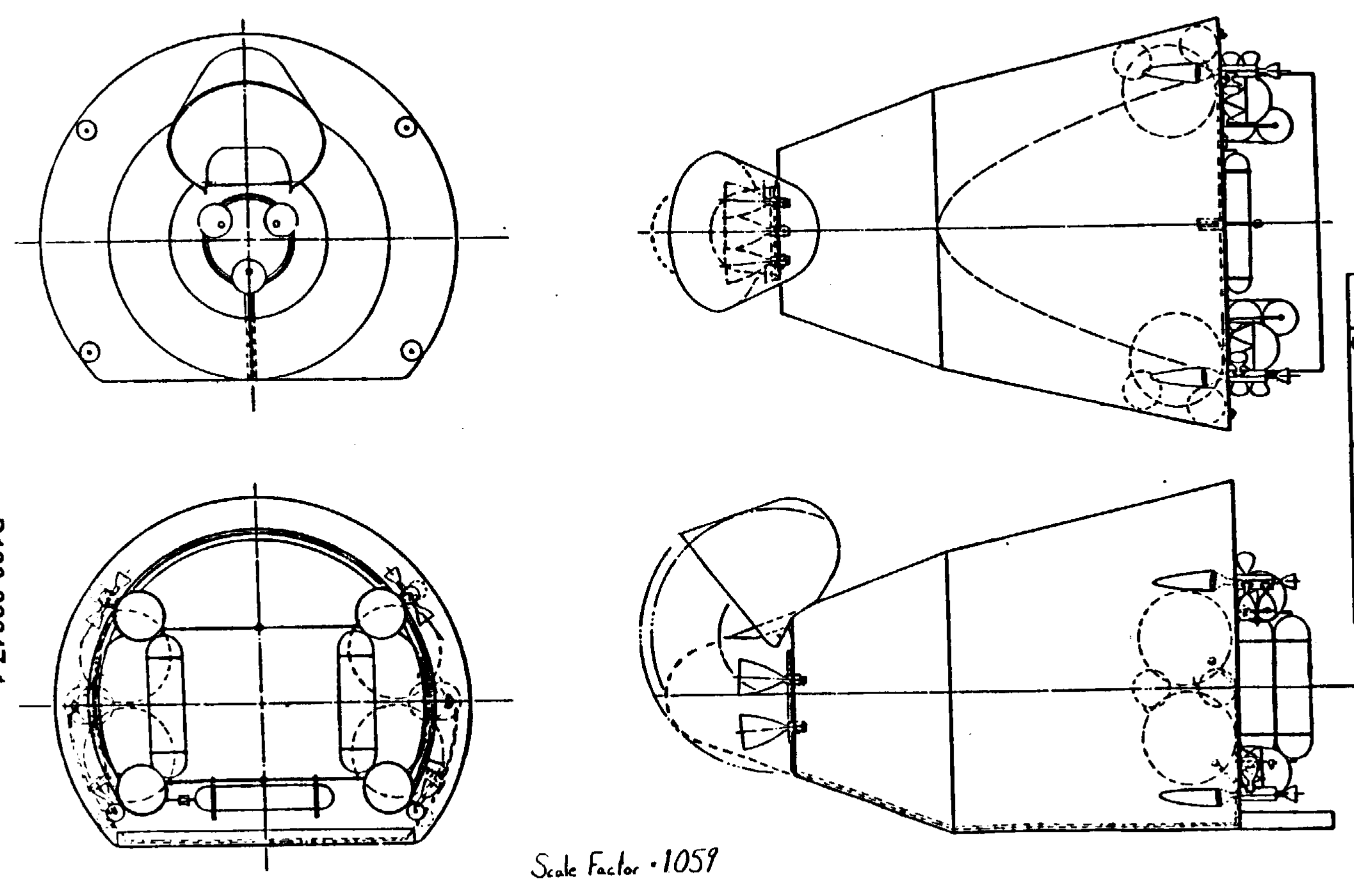
Figure 9.11-2 Propulsion Integration Studies (Page 6 of 10)



Propulsion Element	Reusable	Internal
OMS		
Engines	●	●
Tankage		
RCS		
Thrusters	●	
Tankage	●/O	
Proximity Operations		
Thrusters	●	
Tankage		

Option 19,21

Figure 9.11-2 Propulsion Integration Studies (Page 7 of 10)



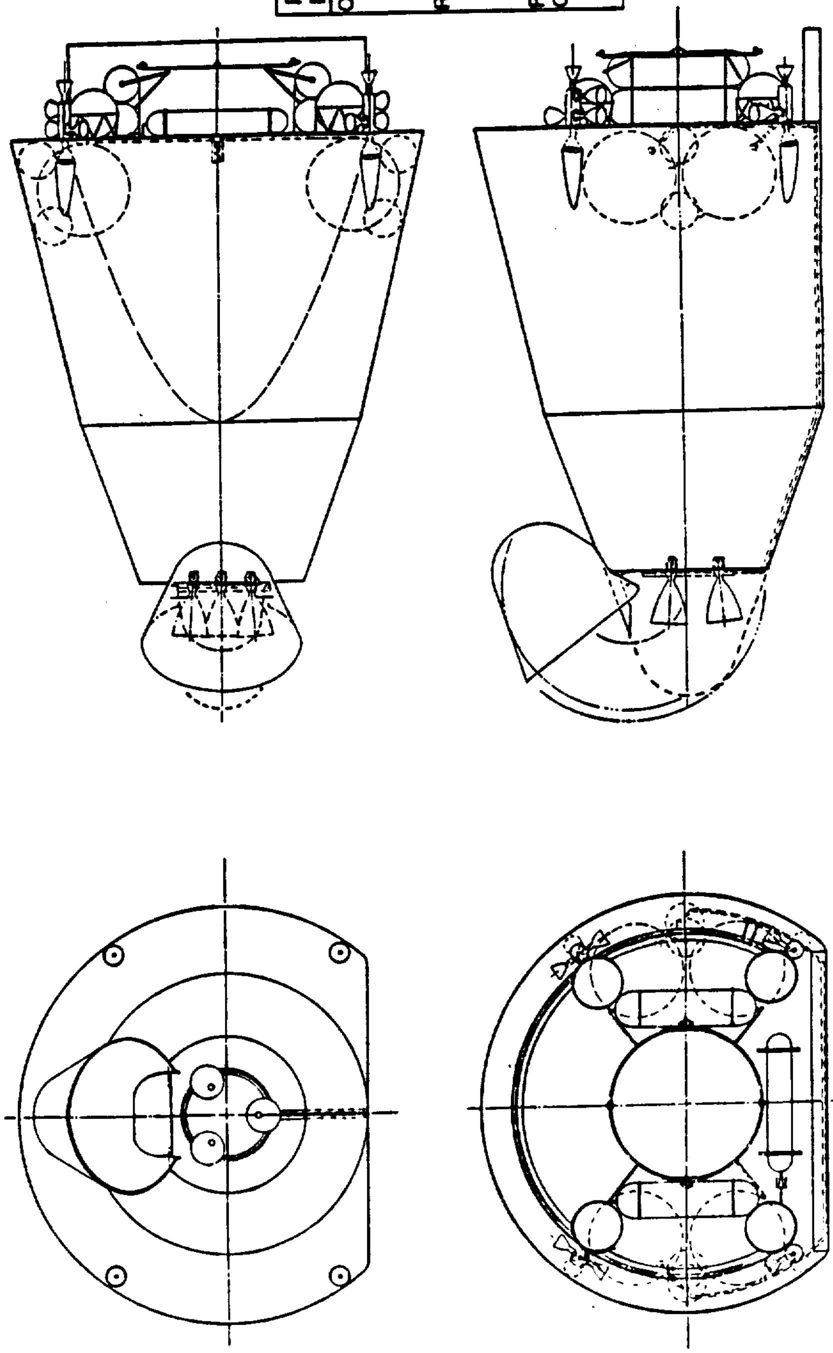
Propulsion Element	Reusable	Internal
OMS		
Engines	●	●
Tankage	●	●
RCS		
Thrusters	●	
Tankage	●	
Proximity Operations		
Thrusters	●	
Tankage		

Option 23

Figure 9.11-2 Propulsion Integration Studies (Page 8 of 10)

Propulsion Element	Reusable	Internal
OMS		
Engines	●	●
Tankage	●	●
RCS		
Thrusters	●	
Tankage	●	●
Proximity Operations		
Thrusters		
Tankage		

Option 31



Scale Factor ·1.059

Figure 9.11-2 Propulsion Integration Studies (Page 9 of 10)

Propulsion Element	Reusable	Internal
OMS		
Engines		
Tankage		
RCS		
Thrusters	●	
Tankage	●/O	
Proximity Operations		
Thrusters	●	
Tankage	●	

Option 13,17

Propulsion Element	Reusable	Internal
OMS		
Engines		
Tankage		
RCS		
Thrusters	●	
Tankage	●	
Proximity Operations		
Thrusters	●	
Tankage	●	

Option 5

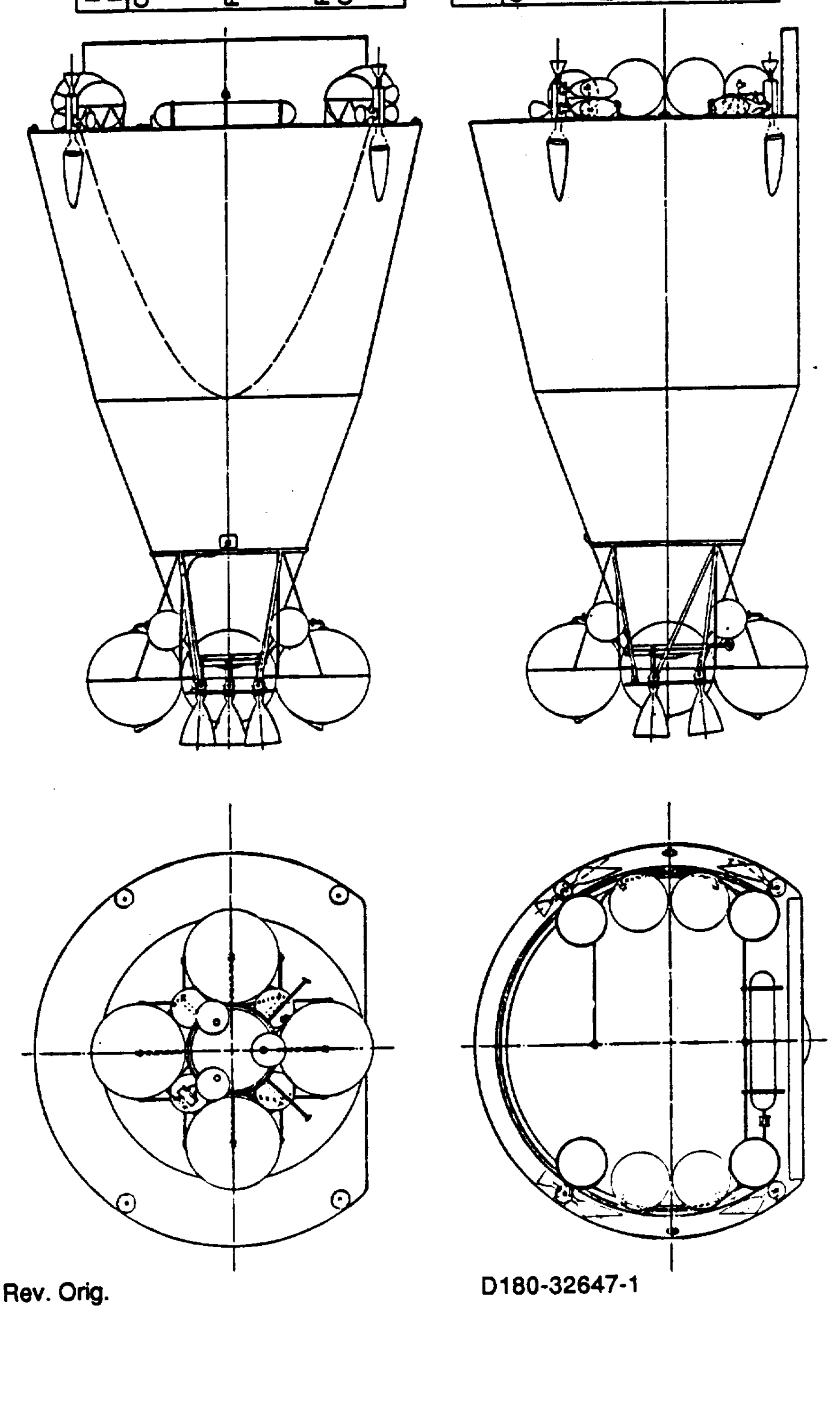


Figure 9.11-2 Propulsion Integration Studies (Page 10 of 10)

Table 9.11-3 Propulsion Reusability Option Weights (Page 1 of 2)

	POD		Option 1		Option 3		Option 5		Option 7		Option 9		Option 11		Option 13		Option 15		Option 17	
	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb
Structure - Point of Departure		4964		4964		4964		4964		4964		4964		4964		4964		4964		4964
Structure - Modifications	a	0	a	0	a	0	a	0	b	196	b	196	c	706	a	0	a	0	a	0
Protection - Point of Departure		1220		1220		1220		1220		1220		1220		1220		1220		1220		1220
Protection - Modifications	a	0	a	0	a	0	a	0	b	28	b	28	c	148	a	0	a	0	a	0
Propulsion - Return OMS	a	0	a	0	a	0	a	0	b	379	b	379	c	1381	a	0	a	0	a	0
Propulsion - Return RCS	c	506	a	727	b	693	c	661	d	819	c	661	c	661	e	738	b	693	c	661
Propulsion - Return Cold Gas System	b	646	a	0	a	0	b	734	b	734	b	734	b	734	c	50	c	50	c	50
Power - Electrical		1743		1743		1743		1743		1743		1743		1743		1743		1743		1743
Surface Controls		121		121		121		121		121		121		121		121		121		121
Avionics		1637		1637		1637		1637		1637		1637		1637		1637		1637		1637
Environmental Control		1406		1406		1406		1406		1406		1406		1406		1406		1406		1406
Other - Personnel Provisions		1700		1700		1700		1700		1700		1700		1700		1700		1700		1700
Other - Recovery & Auxiliary		2509		2430		2396		2539		2686		2665		2877		2462		2427		2453
Weight Growth Margin		2468		2392		2382		2509		2645		2618		2895		2406		2394		2393
Crew Module Dry Weight		**18920**		**18340**		**18262**		**19234**		**20279**		**20072**		**22192**		**18447**		**18355**		**18348**
Personnel/ Consumables Resid		3440		3440		3440		3440		3440		3440		3440		3440		3440		3440
OMS Propellant @ Reentry		0		0		0		0		426		422		439		0		0		0
OMS Pressurant @ Reentry		0		0		0		0		18		18		19		0		0		0
RCS Propellant @ Reentry		409		412		142		417		430		426		451		415		144		413
RCS Pressurant @ Reentry		17		4		1		4		4		4		4		4		1		4
Cold Gas Residuals@ Reentry		226		0		0		229		241		239		257		225		222		224
Crew Module at Reentry		**23012**		**22196**		**21845**		**23324**		**24837**		**24622**		**26802**		**22531**		**22162**		**22428**
Non-Propulsive Consumables		254		254		254		254		254		254		254		254		254		254
Launch Adapter / Radiator Module		2005		2005		2005		2005		2005		2005		2005		2005		2005		2005
Propulsion - Expendable OMS	a	1153	a	1458	a	1458	a	1458	b	909	b	909	c	0	a	1458	a	1458	a	1458
Propulsion - Expendable RCS	c	0	a	0	b	272	c	0	d	0	c	0	c	0	e	0	b	272	c	0
Propulsion - Expendable Cold Gas	b	0	a	1048	a	1048	b	0	b	0	b	0	b	0	c	973	c	973	c	973
Weight Growth Margin - Dry Mass		474		677		717		519		437		437		301		665		706		665
Expended OMS Propellant		3268		3378		3385		3341		2874		2853		2967		3381		3386		3369
Expended OMS Pressurant		80		19		19		19		0		0		0		19		19		19
Expended RCS Propellant		288		298		384		295		298		296		308		298		385		297
Expended RCS Pressurant		0		0		2		0		0		0		0		0		2		0
Expended Cold Gas		149		387		388		153		147		146		143		163		166		162
On- Orbit Gross Weight		**30682**		**31719**		**31777**		**31368**		**31762**		**31522**		**32780**		**31747**		**31787**		**31631**
Propellant Required																				
Total OMS Propellant		3268		3378		3385		3341		3300		3275		3406		3381		3386		3369
Total OMS Pressurant	(N2)	80		19		19		19		18		18		19		19		19		19
Total RCS Propellant - Primary		697		710		384		711		728		722		759		713		385		710
Total RCS Propellant - Secondary		0		0		142		0		0		0		0		0		144		0
Total RCS Pressurant	(N2)	17		4		3		4		4		4		4		4		3		4
Total Cold Gas		374		387		388		383		387		385		400		387		388		386
Propellant Capacity																				
Total OMS Propellant	a	4496	a	4496	a	4496	a	4496	b	4496	b	4496	c	3136	a	4496	a	4496	a	4496
Total OMS Pressurant	a	20	a	20	a	20	a	20	b	20	b	20	c	20	a	20	a	20	a	20
Total RCS Propellant - Primary	c	636	a	636	b	636	c	636	d	636	c	636	c	636	e	636	b	636	c	636
Total RCS Propellant - Secondary	c	0	a	0	b	318	c	0	d	0	c	0	c	0	e	0	b	318	c	0
Total RCS Pressurant	c	6	a	7	b	7	c	6	d	7	c	6	c	6	e	7	b	7	c	6
Total Cold Gas	b	665	a	435	a	435	b	665	b	665	b	665	b	665	c	435	c	435	c	435

Table 9.11-3 Propulsion Reusability Option Weights (Page 2 of 2)

	POD		Option 19		Option 21		Option 23		Option 25		Option 27		Option 29		Option 31	
	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb	Type	Mass - lb
Structure - Point of Departure		4964		4964		4964		4964		4964		4964		4964		4964
Structure - Modifications	a	0	b	196	b	196	c	706	a	0	b	196	b	196	c	706
Protection - Point of Departure		1220		1220		1220		1220		1220		1220		1220		1220
Protection - Modifications	a	0	b	28	b	28	c	148	a	0	b	28	b	28	c	148
Propulsion - Return OMS	a	0	b	379	b	379	c	1381	a	0	b	379	b	379	c	1381
Propulsion - Return RCS	c	506	d	819	c	661	c	661	c	661	d	819	c	661	c	661
Propulsion - Return Cold Gas System	b	646	c	50	c	50	c	50	a	0	a	0	a	0	a	0
Power - Electrical		1743		1743		1743		1743		1743		1743		1743		1743
Surface Controls		121		121		121		121		121		121		121		121
Avionics		1637		1637		1637		1637		1637		1637		1637		1637
Environmental Control		1406		1406		1406		1406		1406		1406		1406		1406
Other - Personnel Provisions		1700		1700		1700		1700		1700		1700		1700		1700
Other - Recovery & Auxiliary		2509		2600		2579		2790		2422		2567		2547		2756
Weight Growth Margin		2468		2529		2503		2779		2381		2517		2490		2766
Crew Module Dry Weight		18920		19393		19187		21306		18255		19298		19092		21209
Personnel/ Consumables Resid		3440		3440		3440		3440		3440		3440		3440		3440
OMS Propellant @ Reentry		0		429		426		443		0		429		426		443
OMS Pressurant @ Reentry		0		18		18		19		0		18		18		19
RCS Propellant @ Reentry		409		426		423		448		411		424		421		445
RCS Pressurant @ Reentry		17		4		4		4		4		4		4		4
Cold Gas Residuals@ Reentry		226		235		233		251		0		0		0		0
Crew Module at Reentry		23012		23946		23731		25911		22109		23613		23401		25560
Non-Propulsive Consumables		254		254		254		254		254		254		254		254
Launch Adapter / Radiator Module		2005		2005		2005		2005		2005		2005		2005		2005
Propulsion - Expendable OMS	a	1153	b	909	b	909	c	0	a	1458	b	909	b	909	c	0
Propulsion - Expendable RCS	c	0	d	0	c	0	c	0	c	0	d	0	c	0	c	0
Propulsion - Expendable Cold Gas	b	0	c	973	c	973	c	973	a	1048	a	1048	a	1048	a	1048
Weight Growth Margin - Dry Mass		474		583		583		447		677		594		594		458
Expended OMS Propellant		3268		2898		2877		2990		3368		2897		2875		2989
Expended OMS Pressurant		80		0		0		0		19		0		0		0
Expended RCS Propellant		288		301		298		310		297		301		298		310
Expended RCS Pressurant		0		0		0		0		0		0		0		0
Expended Cold Gas		149		156		155		152		386		391		388		403
On- Orbit Gross Weight		30682		32025		31785		33042		31620		32012		31772		33027
Propellant Required																
Total OMS Propellant		3268		3327		3302		3433		3368		3326		3301		3432
Total OMS Pressurant	(N2)	80		18		18		19		19		18		18		19
Total RCS Propellant - Primary		697		727		721		758		708		725		719		755
Total RCS Propellant - Secondary		0		0		0		0		0		0		0		0
Total RCS Pressurant	(N2)	17		4		4		4		4		4		4		4
Total Cold Gas		374		391		388		403		386		391		388		403
Propellant Capacity																
Total OMS Propellant	a	4496	b	4496	b	4496	c	3136	a	4496	b	4496	b	4496	c	3136
Total OMS Pressurant	a	20	b	20	b	20	c	20	a	20	b	20	b	20	c	20
Total RCS Propellant - Primary	c	636	d	636	c	636	c	636	c	636	d	636	c	636	c	636
Total RCS Propellant - Secondary	c	0	d	0	c	0	c	0	c	0	d	0	c	0	c	0
Total RCS Pressurant	c	6	d	7	c	6	c	6	c	6	d	7	c	6	c	6
Total Cold Gas	b	665	c	435	c	435	c	435	a	435	a	435	a	435	a	435

From a growth standpoint, the external OMS tankage is an excellent choice. Within the physical constraints of the radiator structure, to which the OMS is attached, the OMS capability could easily grow by an order of magnitude and still use spherical tanks. To the rest of the PLS, this change is "transparent".

The radiator, discussed in Section 9.7.3, is physically too large to stow and is of low enough unit cost to make recovery unwarranted. The parafoils, on the other hand are stored internally for protection (not a major volume item) but are expended because the cost of cleaning, repairing and repacking is probably more than the cost of a "factory fresh" parafoil. The proximity operations system nitrogen bottles are external and expendable; the bottle design is very inexpensive (essentially scuba tanks) and mission to mission modularity requires flexibility in packaging which may be best served with expendable tanks.

The LES system, discussed in Section 10.3, is also expendable, primarily because returning it with the PLS would entail a major weight and volume penalty.

In summary, the preferred concept features the following degree of expendability:

- OMS: external and expendable,
- RCS: external but reusable,
- Proximity Operations System: external expendable tankage,
- Radiator: external and expendable,
- LES: external and expendable,
- EPS: internal and reusable, and,
- parachutes/parafoils: internal and expendable.

10 ABORT CAPABILITY

A given objective of the PLS is to provide for a mission abort capability during all phases of the mission. There exist hazards associated with manned space flight that require provisions for "escape" to ensure the survivability of the crew. These hazards/malfunctions can occur at all stages of the flight; some failures are more significant than others, and tend to be most serious during the following flight regimes:

a. Liftoff/initial acceleration

b. Maximum dynamic pressure (typically M=0.8 to 2.0)

c. Shutdown/staging

d. Terminal deceleration

The impact of any given failure depends upon the flight phase as well as the vehicle altitude and attitude. For example, loss of vehicle propulsion requires immediate abort capability when close to the ground, but not necessarily at high altitude.

Previous studies (Reference 26) have traded many options for escape provision. Of all the options, the clear winner for a vehicle carrying ten people is to physically separate the pressurized crew cab from the rest of the vehicle (typically using a Launch Escape System) and return that cab to Earth intact. To determine the design requirements for such a system, one must first examine what hazards or emergencies would precipitate an abort.

10.1 Hazard Analysis

Major emergencies requiring escape can be grouped in the following categories:

- Explosion/fire
- System failures affecting flight dynamics/control
- Structural failure
- Hazardous environment

The number of hazardous events to be analyzed, as performed in a typical Failure Modes and Effects Analysis (FMEA), is very large, and to some degree difficult to characterize at this conceptual phase of design. A slightly different approach tremendously reduces this analysis: after postulating the situations related to the above listed emergencies, potential causes for these hazardous events are identified. If these potential causes are probable and need to be designed against, then the escape requirements for these events are identified. Using this approach, the impact of vehicle operational differences on the escape system becomes relatively small. For example, if an out-of-control vehicle requires emergency escape in, say 7 seconds, then it is immaterial if the vehicle is out-of-control because of a control system computer failure or a failed thruster valve. Therefore, the calculation of the probabilities of individual failures becomes unimportant. Figure 10.1-1 is a summary of PLS hazards and the estimated times that would be available for escape.

Explosion/fire

Explosive and fire emergencies would result primarily from chemical reactions involving propellants and/or high pressure gas storage (i.e. ECLSS tanks). The reaction rate varies considerably with propellant type, containment/structural arrangement, method of initiation, degree of mixing, and the environment. All explosive reactions, though, are characterized by significantly increased temperature and pressure, which can lead to secondary failure modes. The hazards associated with explosions include:

- Shock Wave/Detonation Wave
- Thermal Radiation
- Shrapnel
- Fireball

The shock wave is a pressure pulse radiating out from the point of explosion. Technically, the shock wave propagates at Mach 1 and contains virtually none of the total energy released in an explosion. The detonation wave, on the other hand, is the violent "blow up" that contains most of the released energy of the explosions (in some cases close to 100%) and typically travels outward at around Mach 10. Both the peak

Flight Phases / Hazard Condition	Pre-Launch ~4h	Launch/initial ascent ~2m	Hypersonic ascent ~6m	Orbital flight 0 to 66h	Re-entry ~45m	Landing/ Post Landing ~1h
Propulsion Systems: Booster Propulsion OMS/RCS Propulsion Fuel lines, valves, pumps, tanks	<1s to 2m <1s to 30s	<1s to 30s <1s to 30s	15s to 1m 1m to 6m <1s to 3	5m to 66h to 66h	5s to 1m 5s to 10s	
Thermal Protection				? to 66h	5s to 10s	
ECLSS Pressurization Oxygen supply Contamination	? to 4h 5s to 30m	? to 5m ? to 2m 5s to 2m	? to 10s ? to 6m 5s to 6m	? to 10s ? to 4h 5s to 30m	? to 10s ? to 45m 5s to 30m	5s to 30m
Aerodynamic devices					1s to 1m	
Collision				10s to 66h		
Chemical Explosion	<1s to 30s	<1s to 30s	<1s to 30s	10s to 12h	10s to 1m	<1s to 30s
Cabin Fire	5s to 30s	5s to 30s	5s to 30s	5s to 30s	5s to 30s	5s to 30s

s = second m = minute h = hour

Figure 10.1-1 Typical Escape Times Available

overpressure and the duration of the pulse are significant. For example, humans will sustain lung damage when experiencing a 15 psi pulse for 0.1 seconds; much higher pressures are survivable if the pulse duration is reduced. Cyrogenic fuels tend to produce detonation waves of short duration and high intensity, propellants such UDMH/N_2O_4 deflagrate with longer periods and lower overpressures. In addition to the danger to humans, structures will subsist if a powerful shock wave is short in comparison to the structural response time.

Thermal radiation damage depends on factors such as heat transfer rate, luminosity, temperature intensity, and spectral distribution. Except for emergencies that are inside or have penetrated the crew pressure vessel, the humans will probably be adequately shielded. However, other components, such as exposed launch escape solid rocket motors, would be significantly affected.

Shrapnel damage depends on design, failure mode, and relative spatial orientation. At the conceptual design level, it may be difficult to assess requirements for crew protection.

Fireballs are maybe the least understood explosive phenomena. Unlike the detonation wave, which is virtually impossible to outrun, previous manned spacecraft escape systems were all sized to avoid the predicted fireball. A fireball is formed as a result of a temporary equalization of gas flow that becomes an isotropic, although highly turbulent, formation of incandescent gases, typically representing only 1 to 5% of the total energy released and can locally travel at speeds up to Mach 5. Avoiding or escaping the fireball reduces hazards due to fragmentation, temperature rise (burning), spectral energy, toxicity, and exposure to unburned propellants. As in the case of thermal radiation, the crew cabin is vulnerable, as is the exposed escape system.

The type of launch vehicle propellant directly sets the requirements for a launch escape system. Table 10.1-1 depicts some representative boosters and the response time that would be available in the event of a catastrophic event. Note the systems that use solid propellants (which are fully mixed oxidizer and fuel) are extremely short. The TNT equivalent column is presented to give a relative sense of the potential explosive force that is available. Figure 10.1-2 shows the TNT equivalent effect in an explosion. Although not all propellant detonations behave as TNT, it is an accepted practice to

Table 10.1-1 Available Response Times for Typical Booster Failures

Booster Options	Propellant Combination	TNT Equivalent	Available Response Time (seconds) Leak	Blast Wave	Fireball
•Titan IV	NTO/A-50 AP/PBAN/Al	20% 100% (595 tons)	0.02-0.05	0.002-0.005 (100%)*	3-10 (liquids)
• Liquid (ALS-type)	LH_2/LO_2	20% (200 tons)	1-5	0.5 (1-5%)*	3-20
• Liquid (S-IC type)	LOX/RP-1	(~100 tons)	1-5	0.5 (1%)*	3-40
• Shuttle C	LH_2/LO_2 AP/HTPB/Al	(1800 tons)	0.02-0.05	0.002-0.005 (100%)*	3-60 (liquids)

* energy converted to deflagration

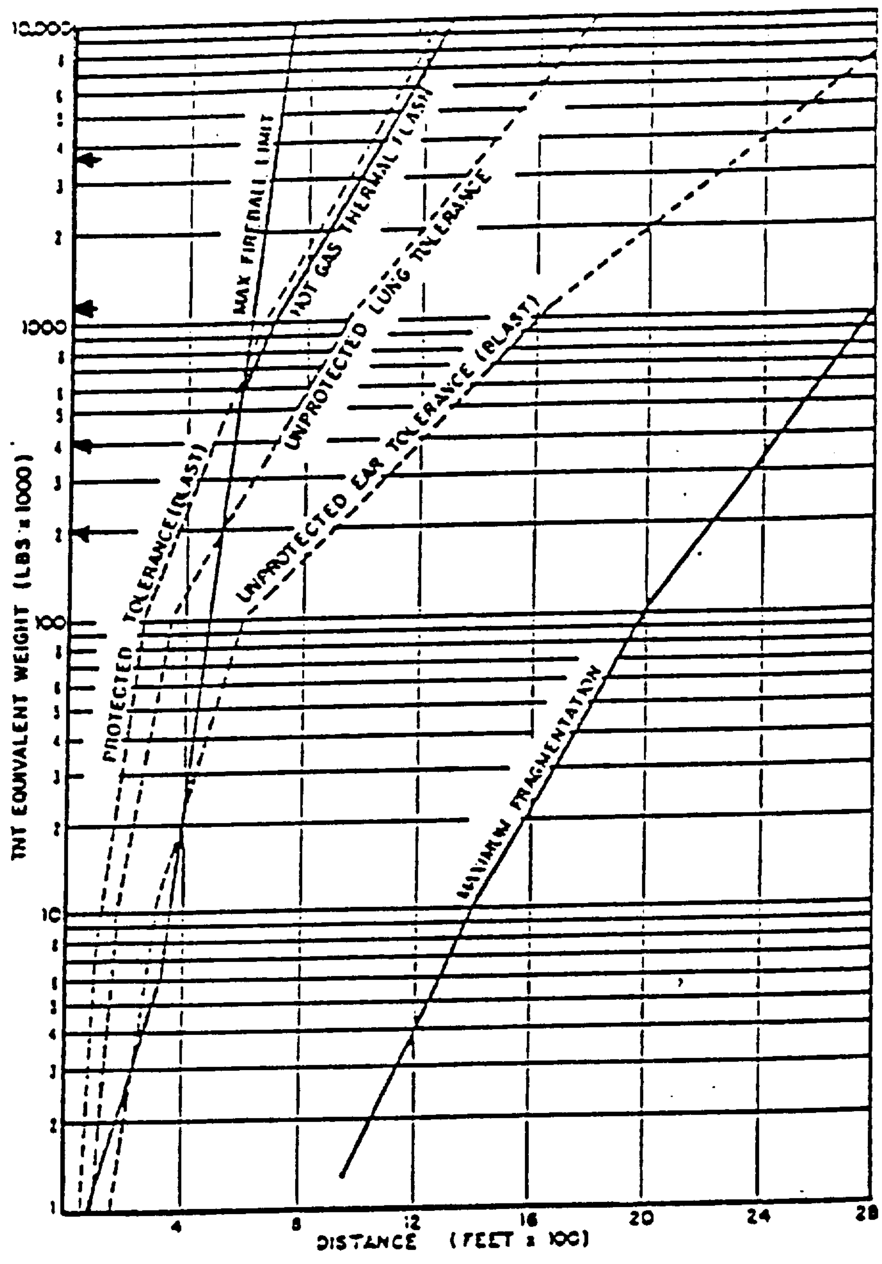


Figure 10.1-2 TNT Equivalent Explosion Effects

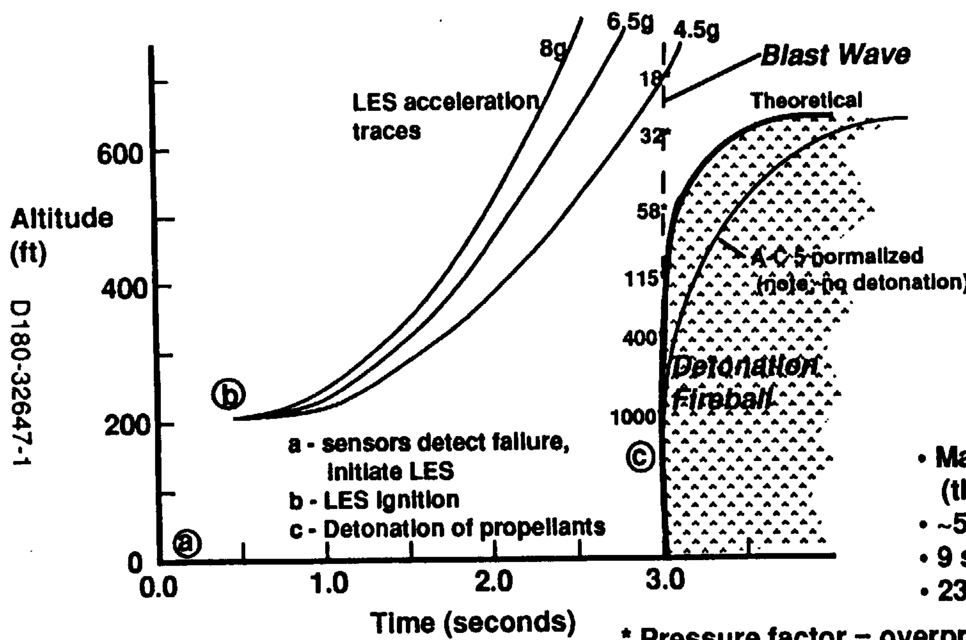
use these equivalents for comparison purposes. For example, various government agencies rate LO_2/LH_2 as 20% to 60% the TNT equivalent by mass.

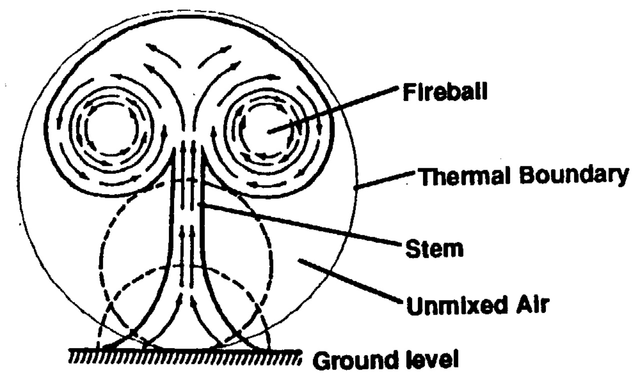
With liquid propellants, it is highly unlikely that the maximum energy potential of an explosion will be encountered. The problem is basically on of incomplete mixing. Even in experiments where full mixing was attempted before detonations, the full potential was never realized. Figure 10.1-3 depicts a time phased altitude plot of a postulated detonation and the warning time required to effect a successful launch escape. In this case, a PLS sits atop an ALS vehicle with close to two million pounds of propellants. At time zero, sensors indicate that a failure is imminent and the LES is initiated. At time 0.5 seconds (conservative by proven systems) the LES ignites and pulls the PLS away (the multiple traces representing various acceleration levels). In this example, the ALS detonates (at 3 seconds representing a typical time between warning and actual detonation) after a hypothetical complete mixing in the region between the oxidizer and fuel tank. The blast wave moves out very rapidly but diminishes quickly. The pressures shown would be attenuated, such that the crew would not feel those values (even a simple aluminum skin would reduce the pressure by an order of magnitude). The fireball would eventually "liftoff", rise and dissipate, but much later, well after the PLS is departed. Note also the normalized curve for an actual Atlas Centaur detonation that doesn't come close to the theoretical worst case. From this example, one can see that with a few seconds warning time, a catastrophic booster detonation should be survivable. With a solid rocket, the detonation point would be moved close to time zero (reflecting the minimal warning time associated with a failure, such as a crack in the propellant) and no LES would be effective.

System failures affecting flight dynamics/control

A failure of a key system on either the PLS or its booster could result in a situation requiring crew escape. Depending on the selected booster(s), an engine shutdown, pump failure, or actuator hard-over could lead to a escape emergency. At any phase of the flight, a control failure (computer, software, actuation, guidance/ navigation, etc.) could render the vehicle out-of-control, and would require escape provisions. Multiple levels of redundancy and improved reliability can reduce the likelihood of a failure, but escape provisions must still be present to account for the improbable and unforeseen.

- ALS 1-1/2 stage launch vehicle with 1,960,000 lbm of cryogenic propellants
- Energy potential converted to deflagration represents an equivalent of 200 tons of TNT





- Maximum adiabatic temperature =7985 °F (theoretical), Project PYRO measured 3860 °F
- ~500 ft maximum radius at "liftoff"
- 9 seconds to "liftoff" of fireball
- 23.7 seconds total duration to snuff

* Pressure factor = overpressure (psi) x attenuation factor

Figure 10.1-3 Altitude versus Time for a Postulated Launch Vehicle Explosion

Structural failure

Failures relating to the physical integrity of the PLS or its booster could result in catastrophic situations that develop in a very small time interval. Boosters are generally long, thin-walled structures that are designed to a specific set of loading requirements. If an unanticipated condition is experienced, such as dynamic pressure, angle-of-attack, wind gust, wind shear, buffet, panel flutter, acoustic, or fuel slosh, a failure will occur, often requiring crew escape (in fact, the Challenger disaster was primarily a structural break up, not an "explosion"). The PLS vehicle itself, while also experiencing the loads imposed by launch and ascent, will also experience loads in orbit, during reentry, and during the terminal deceleration/earth impact. In orbit, the structure is subjected to thermal heating/cooling, one atmosphere pressure differential, and possible collisions with micrometeriods or other space structures. During reentry, the vehicle is subjected to high temperatures as well as dynamic pressure and acoustic loadings. Landing loads include recovery device (e.g. parachute) deployment and impact loads.

Hazardous environment

Hazardous environments, resulting from other failures impacting the crew's environment, may require escape to ensure personnel safety. Failures in the ECLSS or leaks in the propellant supply system represent the most likely scenarios necessitating crew escape.

10.2 Abort Trajectories

The first abort mode involves the use of the Launch Escape System (LES). The crew cab is lifted away from the launch stack with an altitude increase of of approximately 10,000 feet and the vehicle is also sent downrange to clear the launch system. The deceleration device (parachute/parafoil) is deployed around 5,000 feet and the PLS is then recovered. This abort scheme is typically used until the vehicle achieves a perigee altitude of 40-50 nmi. An abort in the early phases will result in the PLS landing in the ocean. When the launch system reaches Mach 10-12 the recovery can be extended to land.

The second major abort scenario is the abort to orbit. The window for this type of abort is very dependent on the booster system. For a typical ALS this abort can occurs as early as liftoff with an engine failure. The PLS is injected into a low (20 by 80-100 nmi.) orbit and the vehicle reenters without any maneuvering.

10.3 Launch Escape System (LES)

Sizing the LES is based on the most demanding energy requirement for successful abort. This case corresponds to the off-the-pad scenario, where the launch vehicle is not moving, but the PLS must ascend to an altitude sufficient for recovery devices to deploy. With the preferred configuration using a parafoil, test data indicates that a minimum of 3000 ft is required to ensure successful parafoil deployment from any attitude. Adding another 2000 ft for conservatism, the LES will require around 606 ft/s ΔV capability to pull to PLS to an apogee of 5000 ft. Figure 10.3-1 shows how the PLS design point compares to the Apollo system. The PLS LES will probably be overdesigned and will approach the performance of the Apollo system.

The requirements for a launch escape system having been established, there are several options to consider. The physical location, interface reusability and propellant/thruster combination must all be considered simultaneously. The object is to incorporate a LES that is the most inexpensive, reliable, and least obtrusive to the rest of the PLS/LV design.

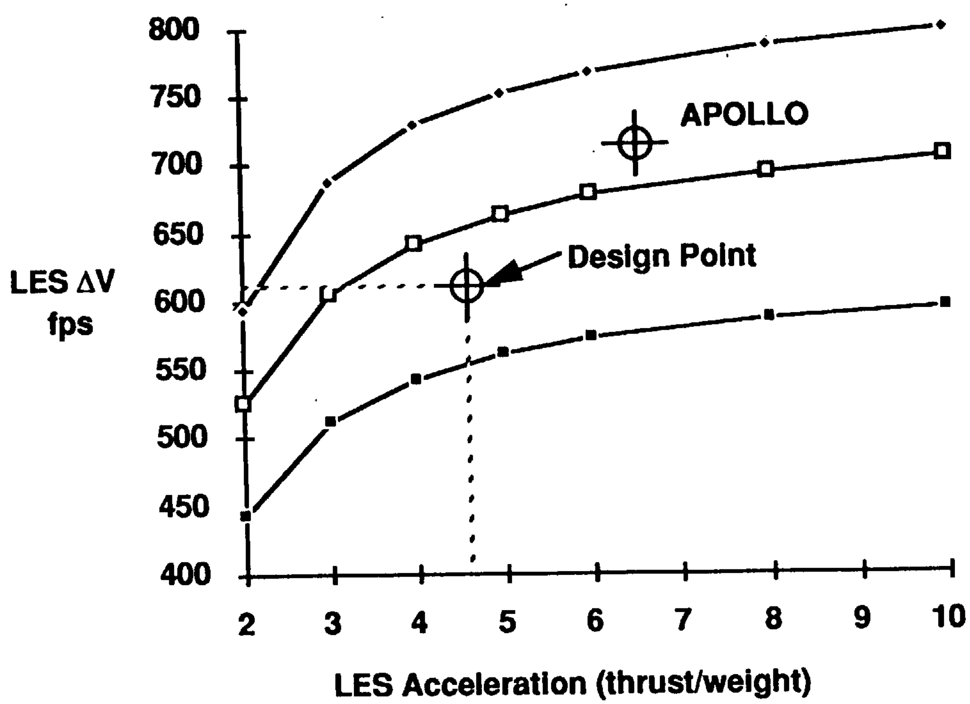
As was the case with the other propulsion systems, there are many solid and liquid propellant options that could be used for a PLS. Previous Systems (Mercury, Apollo, and Soyuz) have all used an expendable solid tractor motor mounted on a dedicated truss/tower. Although not previously demonstrated, a liquid rocket should also perform satisfactorily. Scoring propellant options was done in the same manner as the other propulsion systems (see Table 10.3-1). Some trends can be noted:

- Solid propellant motors require a separate handling facility and are a hazard when integrated onto the PLS/LV stack.
- Multiple solid motors require a reliable simultaneous ignition source or the vehicle could be uncontrollable.
- Pressure-fed liquid rockets would require very heavy tanks and lines.

Table 10.3-1 LES Propellant Weighting Factors

LAUNCH ESCAPE SYSTEM(LES) SCREENING - FOUR OPTIONS AND SEVEN CRITERIA					
SELECTION CRITERIA	WEIGHT FACTOR	SOLIDS AP/HTPB/Al	LO2/RP-1	H2O2/RP-1	NTO/MMH
crew risks	35	20.3	23.8	23.8	18.2
•thermal		2	7	8	8
•separation systems		3	8	8	8
•contamination of crew		4	6	6	3
•fire potential		10	7	8	3
•proven concept		10	6	4	4
cost	20	12	18	16	14
payload/weight	15	1.5	12	15	13.5
ground operations	10	9	6	8	4
damage to test stand	10	6	8	9	8
launch vehicle interfaces	5	5	3.5	4.5	4
volume(stage height)	5	0	4.5	4.5	4.5
	100	53.8	75.8	80.8	66.2

Launch Escape System(LES) sizing is sensitive to minimum parachute opening altitude



•Apogee for off-the pad abort

- 5000 ft altitude
- 7000 ft altitude
- 9000 ft altitude

(For reference, In 1983, a Soyuz LES provided an estimated 1050 ft/sec ΔV and produced a 10 g abort)

Figure 10.3-1 PLS LES Sizing

- Pump-fed liquid rockets require a period of time for pump spin-up before ignition.
- Some liquid propellant combinations require an ignitor (reliability issue).

A matrix of configuration options was developed to explore the interaction between LES, configuration orientation, and OMS/ radiator integration. There are advantages and disadvantages to each arrangement. The eight classes of concepts are shown as Figures 10.3-2 through 10.3-9. A mass comparison is shown as Figure 10.3-10. If minimum mass is essential for launch vehicle compatibility, Concept 1b might be best. The preferred concept, 5c, is a better compromise of operability, growth capability, and cost.

The preferred concept uses an unconventional approach to LES propellants. The OMS propellants, which are physically close to the pusher LES engine, are sized for a larger (yet similar magnitude) ΔV requirement. The OMS tanks would have a separate, larger exit line (around 5 in) that would feed the LES if it was activated. This saves the weight of the extra propellant, and reduces the landing mass of the aborted PLS, as well as essentially purging the OMS before landing and recovery. The expendable LES engine (around 180,000 lbf) would a low cost pump-fed engine designed to operate once for about 4 seconds. On a nominal mission, the engine is thrown away with the launch vehicle adapter when the PLS separates. The resultant weight savings of this system is significant, and was found to be less expensive (see Section 14). The LES equipment list is part of Table 9.3.1.3-1.

Pro:

No major components between the LES and the crew compartments means fewer components and less mass aborted.

Pointed end forward means simpler integration by reducing or eliminating fairings or adapters required.

Pointed end forward reduces airflow turning angles and drag.

Con:

G-loads on crew on launch are thru the blunt end while the G-loads on reentry are thru the pointed end

OMS and docking attachments are both on the vehicle blunt end. During approach, the OMS plume impinges on object being approached.

OMS access is thru the radiator.

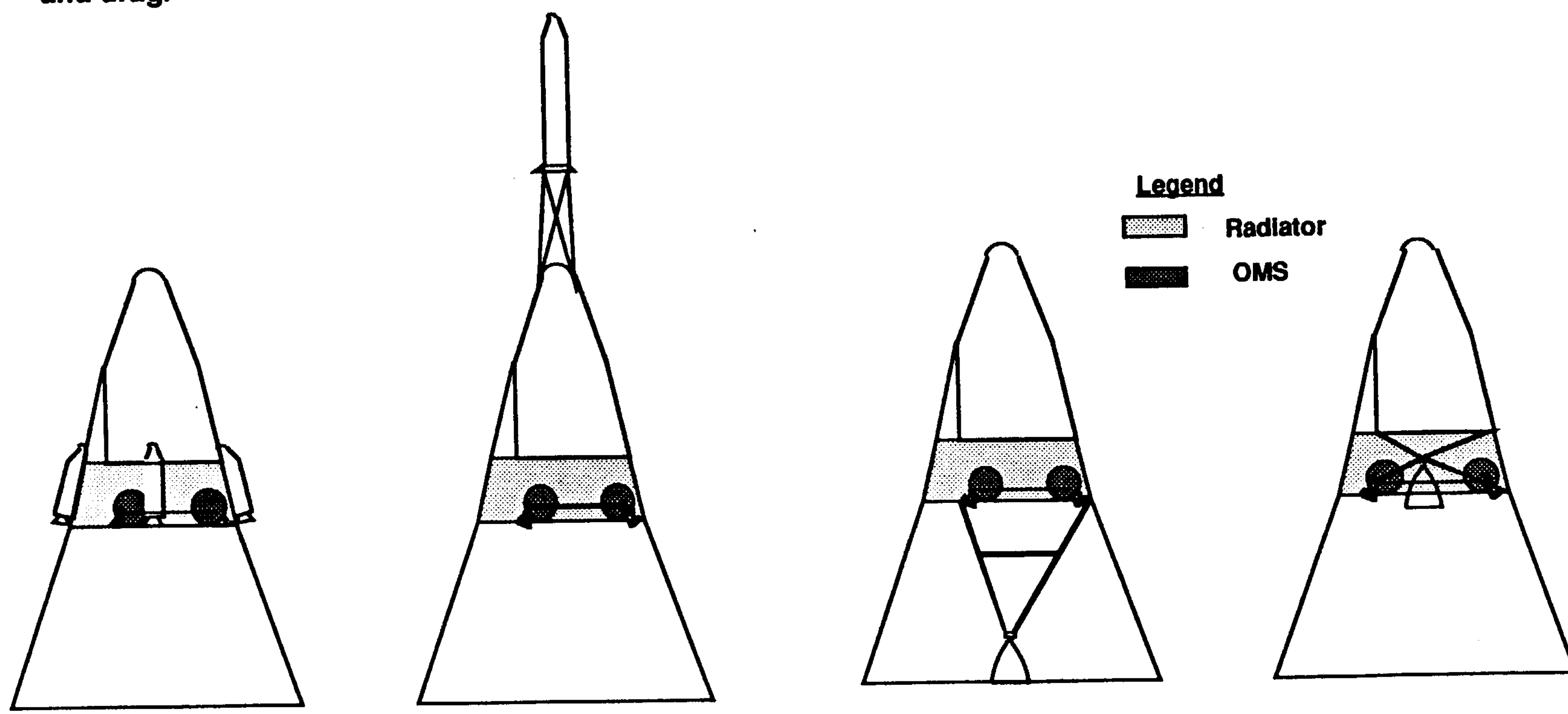


Figure 10.3-2 PLS/LES Configuration Option 1

Pro:

Clear blunt end means no interference during docking.

Flat separation plane between PLS and launch vehicle adapter allows clean separation from booster

Con:

Major components on the nose of the crew compartment means high abort weight.

G-loads on crew on launch are through the blunt end while the G-loads on reentry are through the pointed end.

Multiple flow turning angles increase launch vehicle drag.

OMS access is through the radiator.

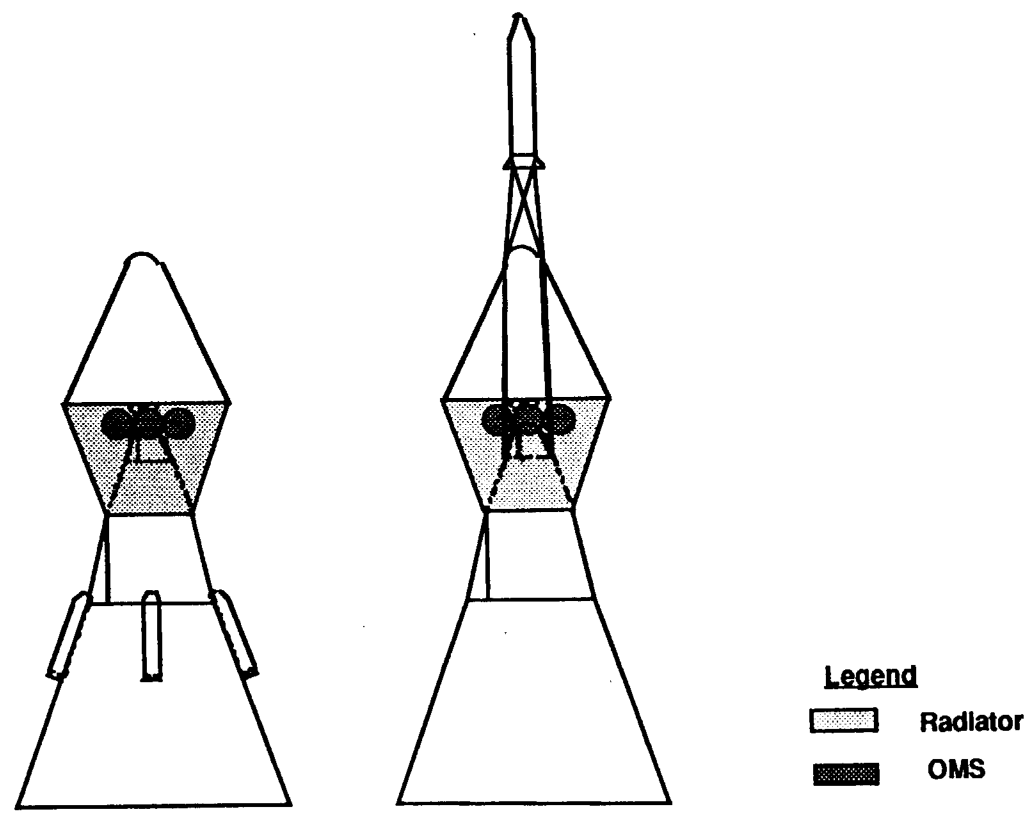


Figure 10.3-3 PLS/LES Configuration Option 2

Pro:

Pointed end forward means simpler integration by reducing or eliminating fairings or adapters required.

Pointed end forward reduces airflow turning angles and drag.

Flat separation plane between PLS and launch vehicle adapter allows clean separation from booster.

OMS tanks easily accessible through the forward fairing.

Con:

Major components on the nose of the crew compartment means high abort weight.

G-loads on crew on launch are through the blunt end while the G-loads on reentry are through the pointed end.

Radiator on blunt end interferes with vehicle docking

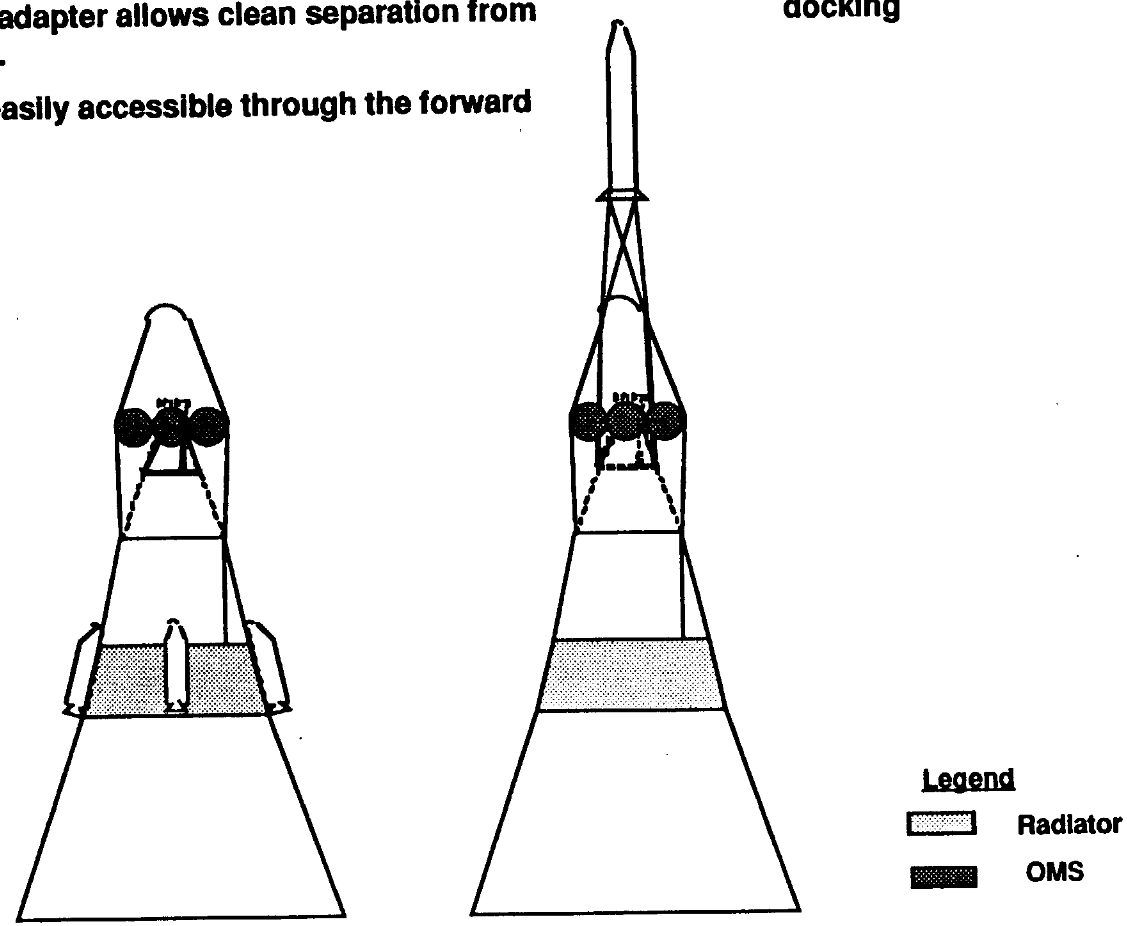


Figure 10.3-4 PLS/LES Configuration Option 3

Pro:

Flat separation plane between PLS and launch vehicle adapter allows clean separation from booster.

The radiator is the only component which would be aborted with the crew compartment yielding one of the lighter weight aborts.

OMS tanks easily accessible through the aft fairing.

Con:

G-loads on crew on launch are through the blunt end while the G-loads on reentry are through the pointed end

OMS and docking attachments are both on the vehicle blunt end. During approach, the OMS plume impinges on object being approached.

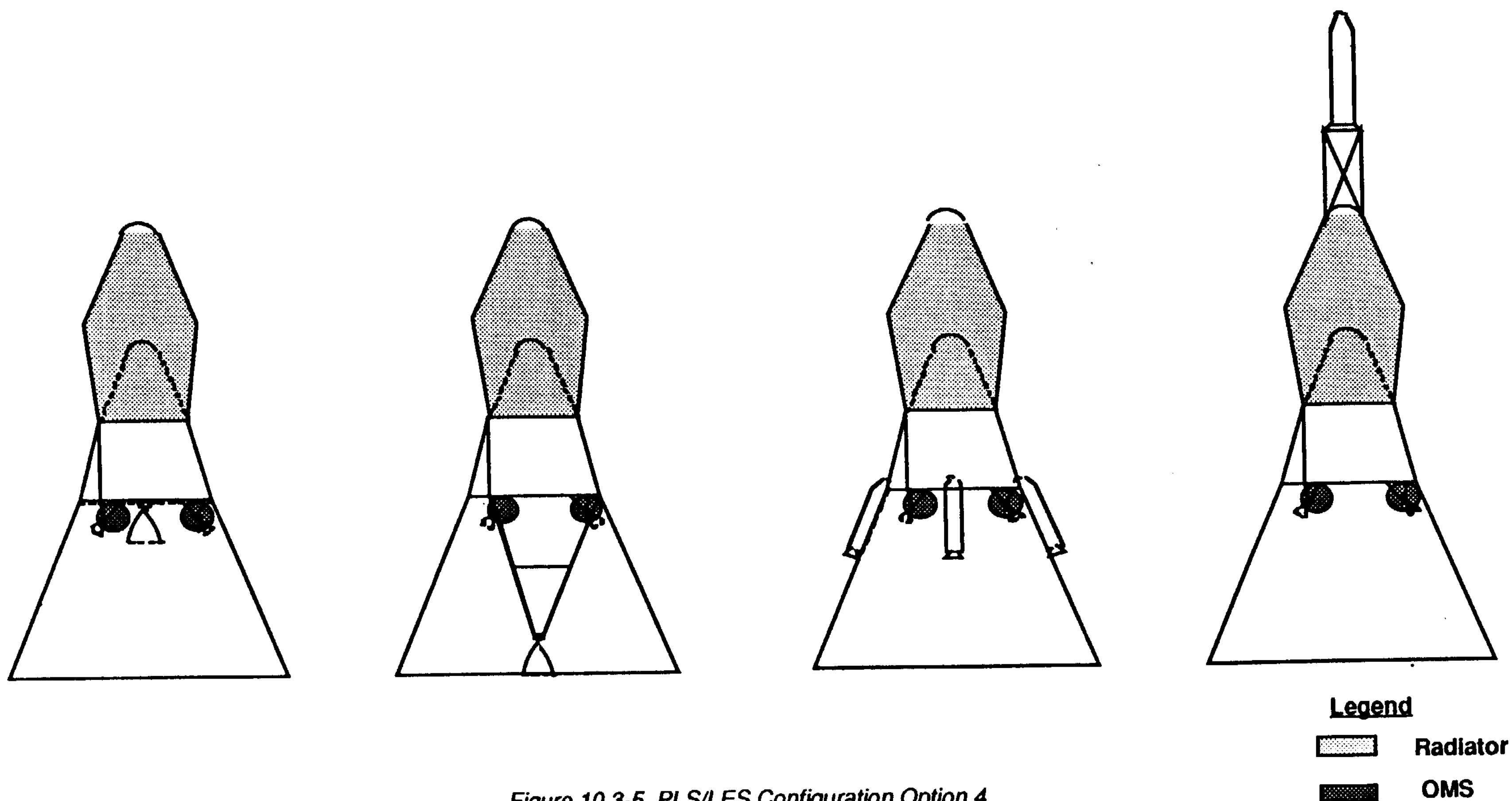


Figure 10.3-5 PLS/LES Configuration Option 4

Pro:

Clear blunt end means no interference during docking.

G-loads for both reentry and launch are through the pointed end.

The fairing is the only component which would be aborted with the crew compartment yielding one of the lighter weight aborts.

Flat separation plane between PLS and launch vehicle adapter allows clean separation from booster

Con:

Multiple flow turning angles increase launch vehicle drag.

OMS access is through the radiator.

Multiple flow turning angles increase launch vehicle drag.

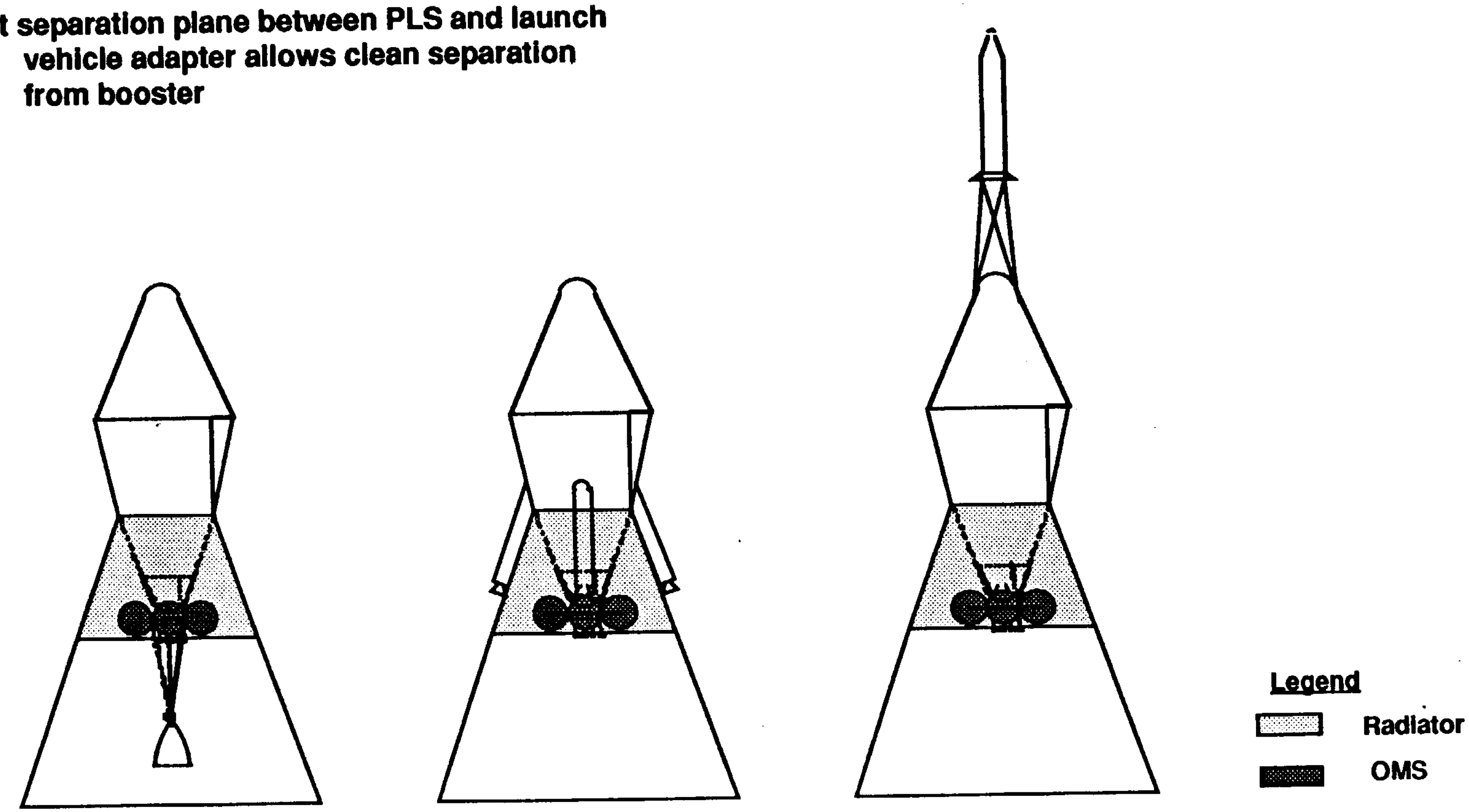


Figure 10.3-6 PLS/LES Configuration Option 5

Pro:

G-loads for both reentry and launch are through the pointed end.

Flat separation plane between PLS and launch vehicle adapter allows clean separation from booster

Con:

OMS and docking attachments are both on the vehicle blunt end. During approach, the OMS plume impinges on object being approached.

Multiple flow turning angles increase launch vehicle drag.

OMS access is through the radiator.

Radiator is on the blunt endand will interfere with docking plane and can lead to heat contamination of docked object.

All components would have to be aborted giving this configuration the highest abort weight.

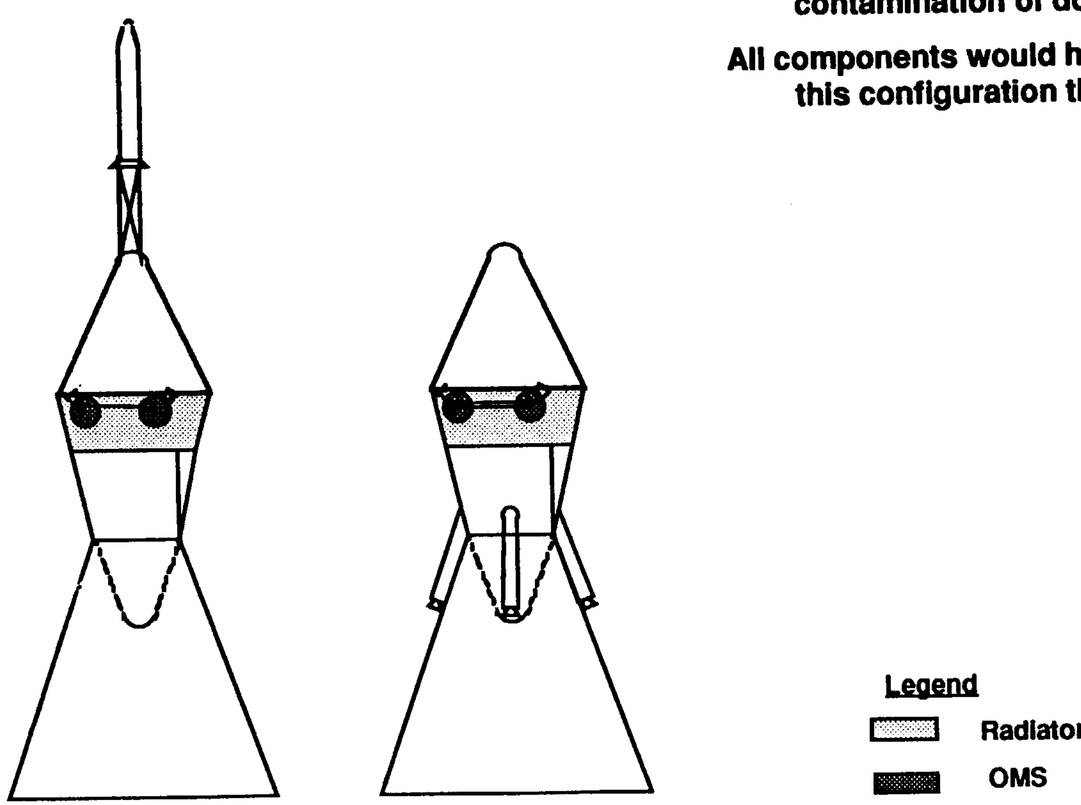


Figure 10.3-7 PLS/LES Configuration Option 6

Pro:

G-loads for both reentry and launch are through the pointed end.

Flat separation plane between PLS and launch vehicle adapter allows clean separation from booster

Con:

OMS and docking attachments are both on the vehicle blunt end. During approach, the OMS plume impinges on object being approached.

Multiple flow turning angles increase launch vehicle drag.

OMS would have to be aborted giving this configuration a high abort weight.

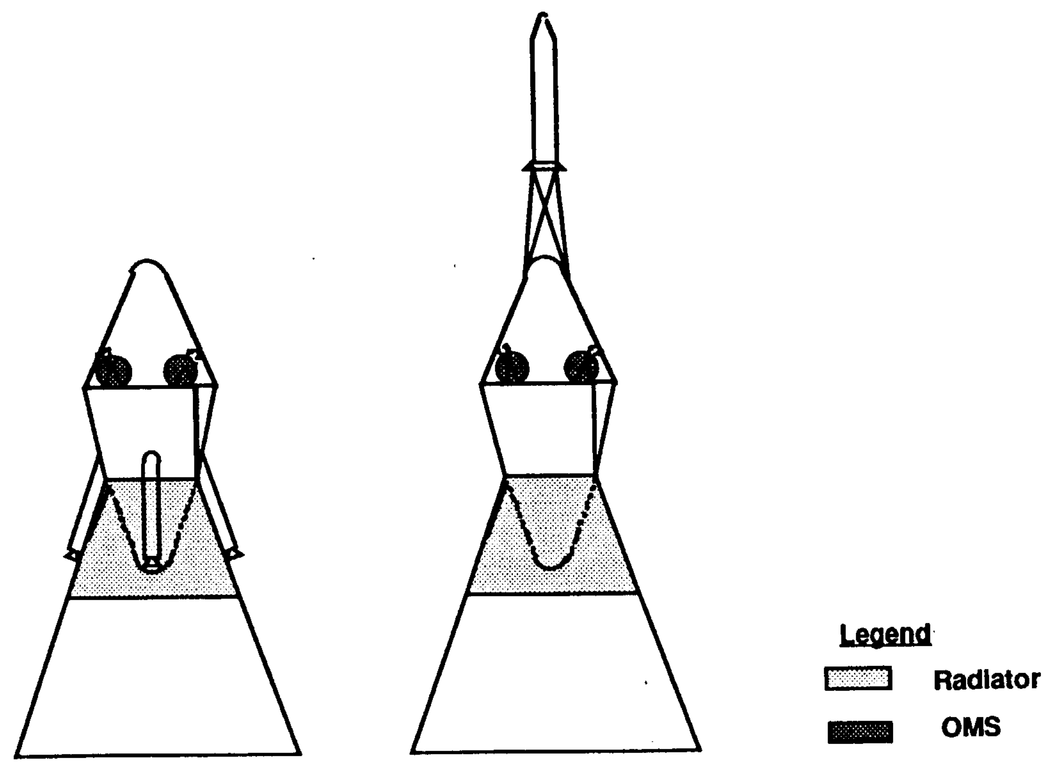


Figure 10.3-8 PLS/LES Configuration Option 7

Pro:

G-loads for both reentry and launch are through the pointed end.

The radiator and fairing are the only components which would be aborted with the crew compartment yielding one of the lighter weight aborts.

Con:

Multiple flow turning angles increase launch vehicle drag.

Radiator is on the blunt end and will interfere with docking plane and can lead to heat contamination of docked object.

Top of the launch vehicle adapter is narrower than the OMS, this makes the launch vehicle separation more complex, i.e. a clamshell separation mechanism.

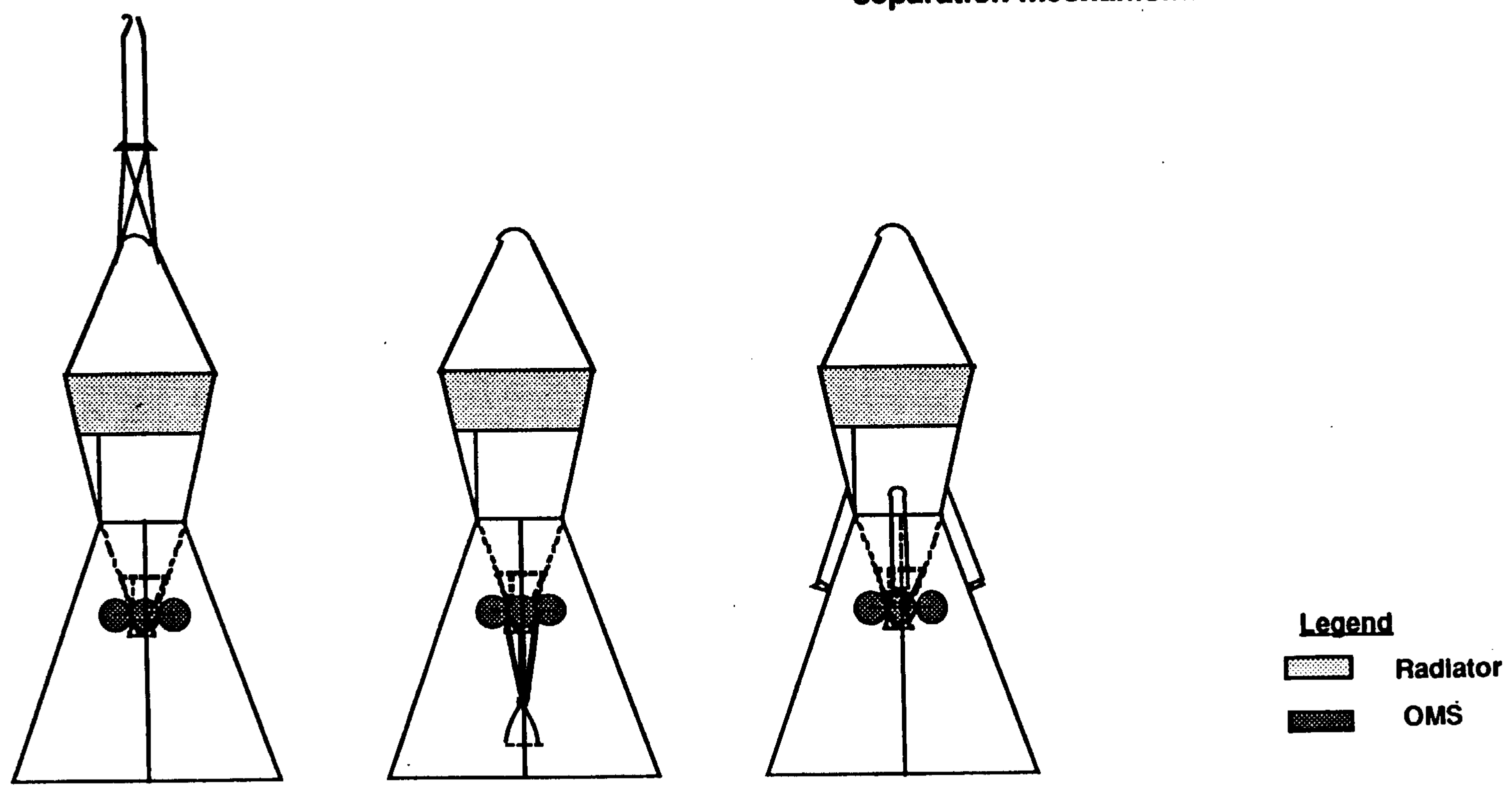


Figure 10.3-9 PLS/LES Configuration Option 8

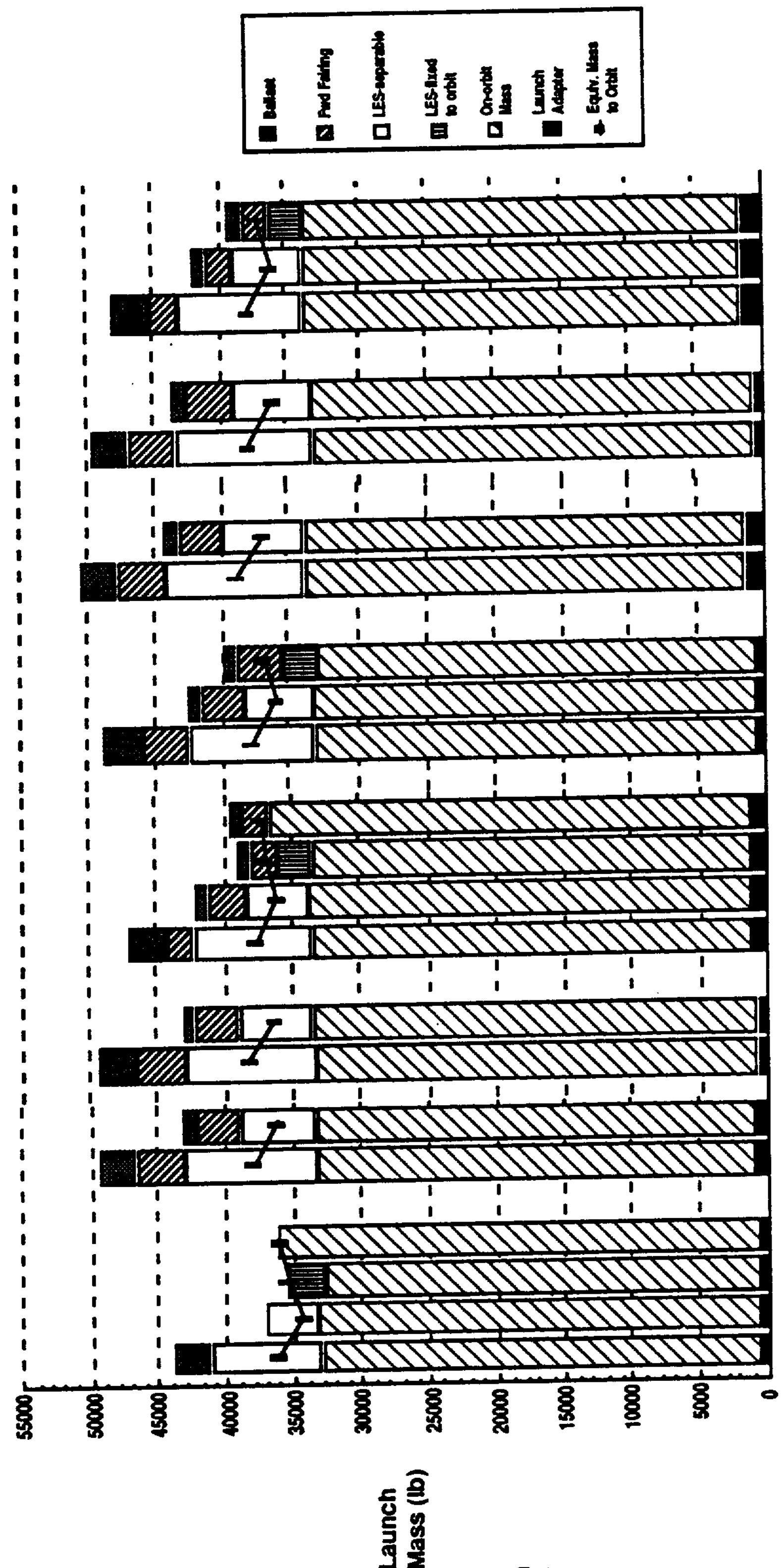


Figure 10.3-10 PLS/LES Configuration Option Mass Comparison

11 LAUNCH VEHICLE INTEGRATION

The PLS vehicle is delivered to an initial low Earth orbit (nominally 80 x 150 nmi) by a launch vehicle. The inclination of this orbit will be very close to the final objective inclination as the PLS OMS is not sized for extensive plane changes. The launch vehicle options must have adequate performance capability and must be available at the desired flight rate and at an acceptable cost. The issues of availability and cost are not discussed here but must eventually be addressed.

The selected configuration arrangement features a forward launch fairing, the reusable crew module, an expendable radiator/ OMS module, and an expendable LES engine (see Figure 11.0-1). The combined mass of these elements is 37,568 lbm. The launch vehicle would be fitted with a cylindrical or conical adapter upon which the radiator module would sit.

11.1 Launch Vehicle Options

The mass of the PLS represents a significant payload size for a booster to lift. Minimum weight was not <u>the</u> design driver, as robustness is more consistent with an operationally successful vehicle, but tends to increase system weight. In either case, selecting a booster that is just capable enough to do the current mission limits the growth potential of the system and thus decreases system effectiveness.

Since the PLS is a manned vehicle, it is desirable to keep the acceleration forces to a minimum during ascent. Most of the current or envisioned stable of liquid rocket boosters are acceptable; some solid rocket boosters can produce uncomfortably high "g" forces.

As was discussed in the previous section (specifically, Section 10.1), any launch vehicle option that includes solid propellants will have failure modes that will not be survivable. To be consistent with program goals of enhances safety, therefor, the selection of any launch vehicle that uses a solid motor should be questioned.

There is only one existing US launch vehicle capable of lifting the PLS - the Titan IV (which does include solid boosters). Figure 11.1-1 shows the Titan IV with a PLS and the performance of the booster. The radiator/OMS module angles are the same are not optimized for use on a Titan - if the Titan were the booster of choice, the double

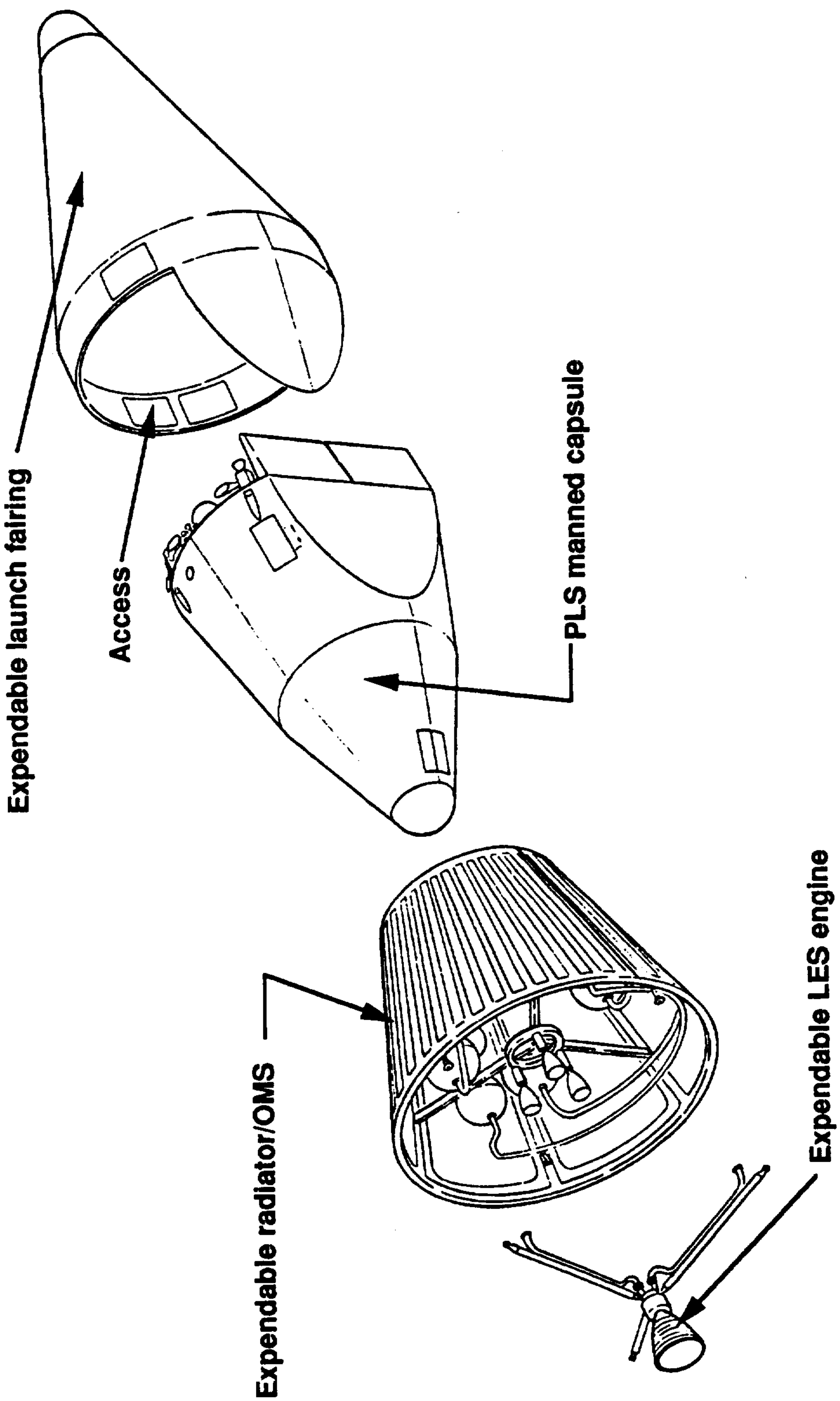
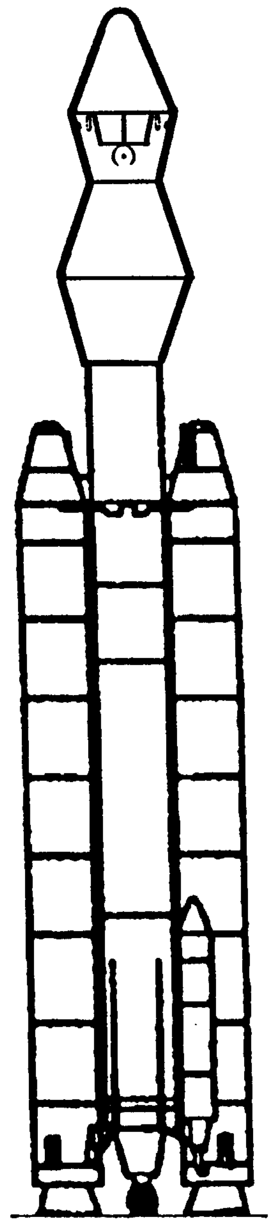


Figure 11.0-1 PLS Launched Componenets



Orbit	Payload weight *	Payload
28.5 deg	48.000 lbs	PLS + 10,432 lbs
57 deg	TBD lbs	N/A
70 deg	TBD lbs	N/A
90 deg	TBD lbs	N/A
98.7 deg	TBD lbs	N/A

* With ASRMs

Figure 11.1-1. PLS on Titan IV

hammerhead shape would probably be eliminated. Note that any missions to an inclination greater than the SSF could not be accommodated!

The other launch vehicle options can be divided into two types: foreign launch vehicles and proposed US launch vehicles.

If the United States decided it was politically acceptable to launch on another countries booster, there could be low-cost alternatives available. In addition, scheduling issues and facilities availability at KSC could be eased. The Soviet Proton rocket has been flown for 25 years (well along the learning curve) and has a performance level sufficient to place the basic PLS at the SSF. In addition, the Ariane V, currently under development for ESA, also should possess enough performance to SSF. Neither of these options has a real surplus of lift capacity; growth PLS versions would probably not be able to use them.

A new liquid booster in the US seems likely in the near future. One possibility would be a derivative of the Liquid Rocket Booster (LRB), or a Hybrid Booster, currently under study as a replacement for the STS SRB. Figure 11.1-2 was an concept studied at MSFC using LRBs as PLS launchers. Another possibility would be to use an Advanced Launch System (ALS) vehicle currently under NASA/USAF development. Figures 11.1-3 and -4 show a 1.5 and a 2 stage ALS respectively with a PLS. There is, as the vehicles are currently sized, some excess performance capability that will enable mission growth. A final alternative might be a dedicated PLS launcher, "optimized" for safety and/or operability, not performance. Such a system would probably look much like the envisioned ALS, since it is an all liquid system designed for high reliability and engine-out operability.

11.2 Launch Vehicle Interfaces

Regardless of the launch vehicle selection, there are several issues concerning integration that must be addressed. Generally, these issues include: structural, aerodynamic, data, safety/abort, and operations.

Physically, the PLS sits atop the launch vehicle. An adapter section carries the loads (both static and flight loads) between the launch vehicle diameter and the bottom of the PLS radiator module. The selection of an axisymmetric PLS greatly simplifies the adapter design as well as its cost. During assembly and during separation, it is desirable to keep the separation in one plane; again, the simple axisymmetric shapes

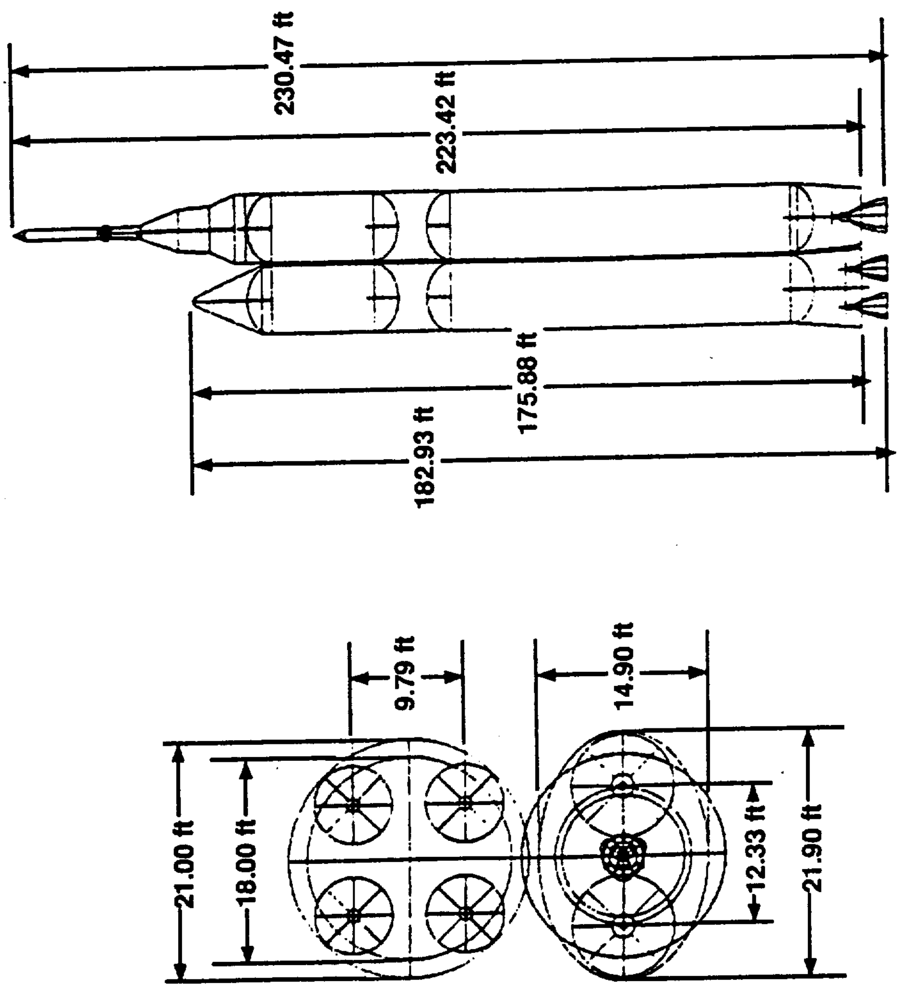
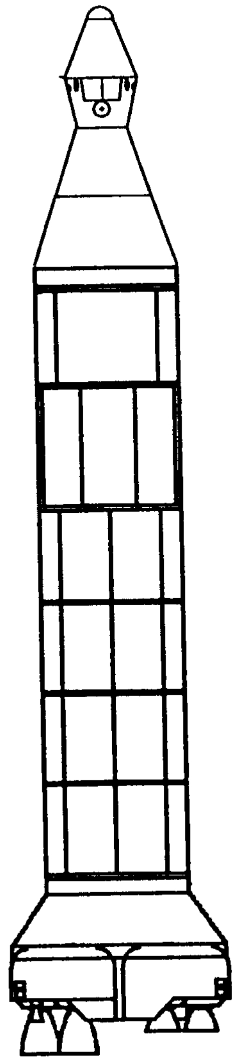


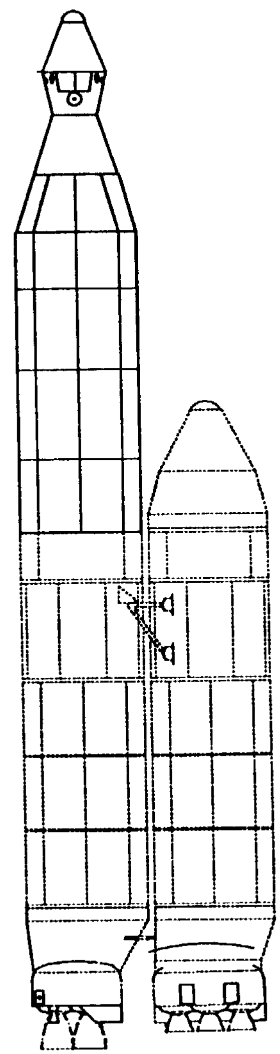
Figure 11.1-2. MSFC Concept for PLS on LRB



PERFORMANCE SUMMARY

Orbit	Payload
28.5 deg	58,000 lbs (PLS + 20,432 lbs)
57 deg	43,245 lbs (PLS + 5,677 lbs)
70 deg	39,520 lbs (PLS + 1,952 lbs)
90 deg	31,455 lbs (No PLS capability)
98.7 deg	28,045 lbs (No PLS capability)

Figure 11.1-3 PLS on 1.5 Stage ALS



PERFORMANCE SUMMARY	
Orbit	**Payload**
28.5 deg	136,545 lbs (PLS + 98,977 lbs)
57 deg	111,345 lbs (PLS + 73,777 lbs)
70 deg	106,740 lbs (PLS + 69,172 lbs)
90 deg	96,375 lbs (PLS + 58,807 lbs)
98.7 deg	92,005 lbs (PLS + 54;437 lbs)

Figure 11.1-4 PLS on 2 Stage ALS

permit the use of proven ring frame to ring frame joints. If multiple launch vehicle types are to be used for PLS, the design of the adapters will be different.

Aerodynamic forces, such as lift and drag, are created as the launch vehicle/PLS ascends through the atmosphere. These forces will produce bending loads across the joints and will require control, most likely thrust vectoring, to steer the combination. In addition vibrations and local shock impingement heating can occur due to geometry. While any comparison awaits detailed study in the future, it can be said that the axisymmetric shape and small physical size of the PLS should result in forces well within the capability of the launch vehicle options. A nonsymmetric, lifting shape could be a problem in certain gust conditions. The hammerhead type slope change in the biconic PLS design shown here is not unprecedented, and is physically less obtrusive than many envisioned payload fairings.

Data transfers must be provided for. This data is typically information concerning the health of the launch vehicle which the PLS will use to determine when an abort might be necessary. In the other direction, some commands may be initiated from the PLS (such as an engine shutdown) to the launch vehicle. At present, launch vehicles are not designed to "talk" to their payloads in this fashion and may require changes to the launch vehicle design. While it is probably undesirable to enable the PLS to "fly" the launch vehicle (a capability that did exist in some previous programs when avionics were less capable), the PLS should have the capability of assessing the health and safety of the launch vehicle without depending on a ground communications link. While the volume and type of data is not yet defined, it would be fairly certain that different launcher types would provide significantly different data (and probably a different physical connection). Any thought then, of using multiple launch vehicle types must account for either a loss in data transmittal capability and/or the inclusion of a smart interface device.

For manned safety, a launch escape system (LES) is provided for with the PLS. It is desirable that the capability exists to terminate the launch vehicle's thrust from a command in the PLS. Clean separation planes and simple structural interfaces ensure the PLS will not contact the launch vehicle during a normal or abort separation.

Operations involving a PLS/launch vehicle are here defined as the time after the PLS is mated to the launch vehicle (LV) until they separate near low Earth orbit. Most concepts involve mating the PLS/LV inside a facility near a launch pad, and moving

the combination to the fueling/launch site. In addition to the interface issues previously discussed, manned spacecraft have a significant impact on the launch site design. A tower is usually adjacent to the launch vehicle. This tower must also include access arms to the PLS for crew ingress and any on-pad servicing. In addition, emergency egress provisions (such as a slide wire to a sheltered bunker) must be included. The PLS should be located on the launch vehicle in an orientation that will permit the simplest access to the tower.

11.3 Trajectories

To investigate ascent performance, ther were two tools that were used. These tools are the Special Performance Optimization Tool (SPOT) and the Optimal Trajectories by Implicit Simulation (OTIS) program. These codes are 3 degree of freedom (no rotational dynamics) point mass analysis tools. Both codes can be used to provide detailed trajectories for ascents. User supplied tabular data are used to model the vehicle's aerodynamic, and propulsion characteristics. Vehicle constraints can be imposed. The constraints are imposed by the various subsystems such as:

Structures (dynamic pressure limits and q-alpha limits),

Control System (attitude rate limits),

Personnel (acceleration limits),

Range Safety (overflight constraints, which may require turns such as the so called dogleg maneuvers)

Mission Constraints (final position and altitude).

Both SPOT and OTIS will allow a user to generate the attitude (pitch) profile to inject the PLS into orbit. These codes are also used to determine when the the various abort modes can be employed. An example ALS-type launch vehicle trajectory is shown as Figure 11.3-1.

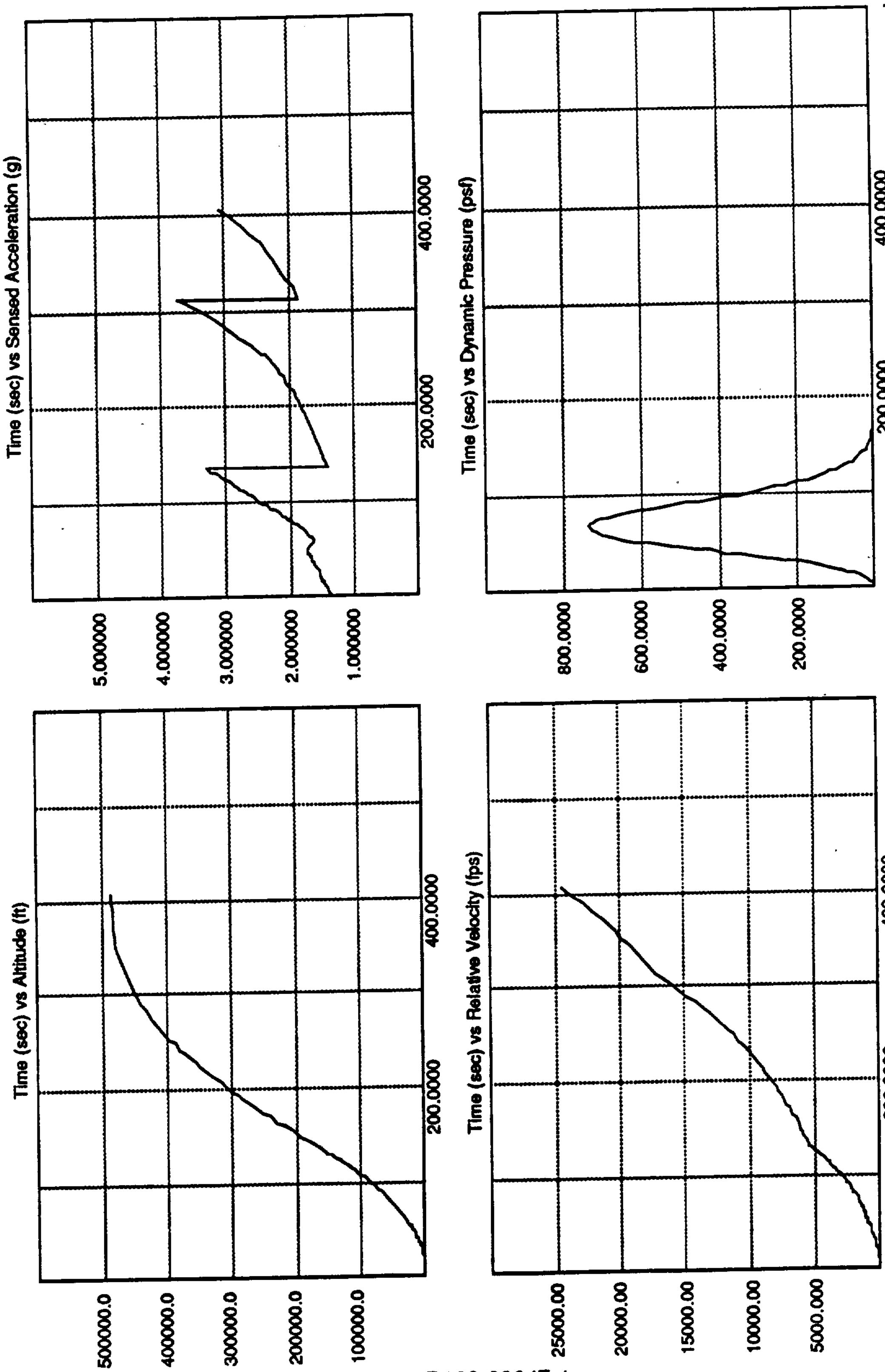


Figure 11.3-1 Typical Ascent Performance (Page 1 of 2)

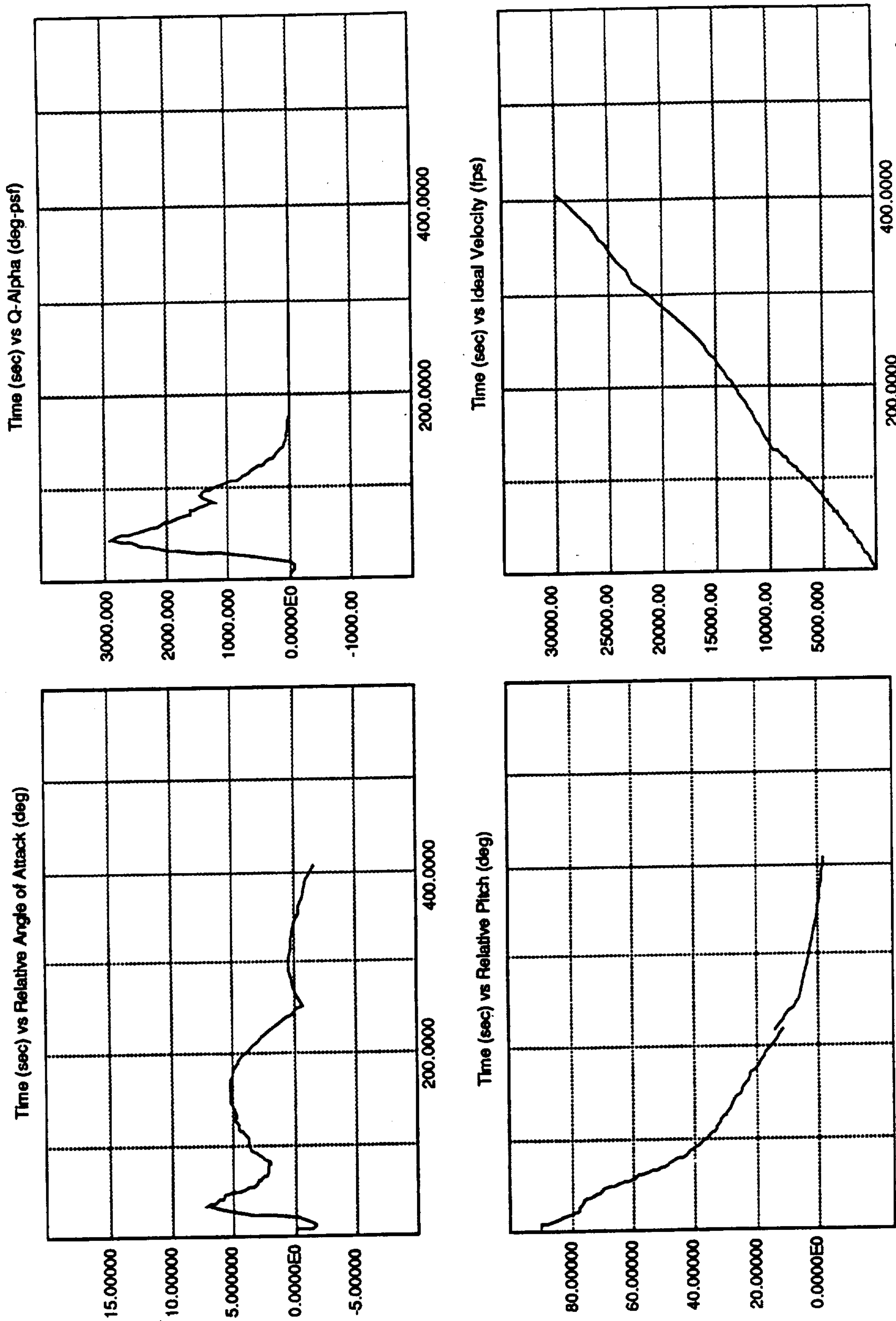


Figure 11.3-1 Typical Scent Performance (Page 2 of 2)

12 FLIGHT SUPPORT AND GROUND OPERATIONS

It is possible at a conceptual level to outline the procedures for flight support and ground operations, including launch abort strategies and procedures. These procedures, along with a definition of operational functions and facilities needed for flight support and ground processing form the basis for operations cost analysis and comparison. Innovative operational approaches have been identified (also found in Section 2) and are important in defining an efficient Personnel Launch System.

12.1 Operational Requirements

PLS operational requirements are derived using a standard Systems Engineering methodology of determining objectives, developing agreed to groundrules, postulating functional flows and then deriving and allocating operational requirements. The salient points of a design philosophy, "Design for Operations", which facilitates the satisfying of the derived requirements are stated in this section.

Groundrules - the operational groundrules used throughout the flight support and ground operations analysis are as listed here for reference. They were extracted or derived from the Statement of Work or were provided as separate inputs from JSC:

- routine manned access to LEO,
- FSD commencing 1992, operations through the year 2020, 20 years minimum system life,
- primary launch site will be KSC, other launch sites used if compatible with the selected launch vehicle,
- no explicit requirement for carrying accompanying payloads,
- number of crew and passengers determined by mission requirements,
- the PLS must provide for crew escape in the event of a launch vehicle failure; emergency egress provisions provided for on the pad or other flight regimes,
- passengers must not be subjected to detrimental acceleration loads,

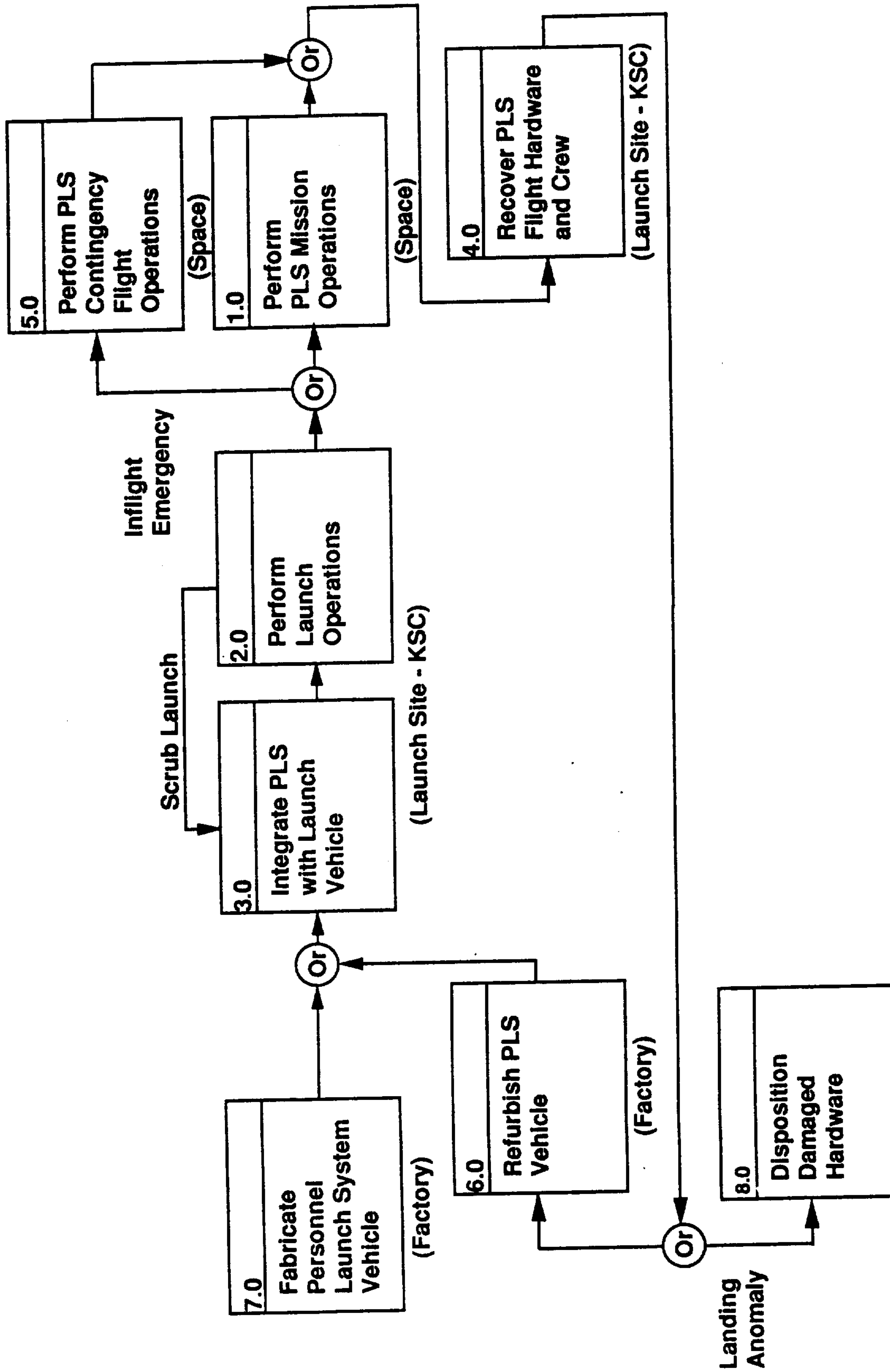


Figure 12.1-1 Top Level Functional Flow

- Function 7.0, Fabricate Personnel Launch System Vehicle - this function produces the vehicle hardware. It includes the manufacture of new hardware and the assembly of subassemblies, assemblies and components into a space vehicle.

- Function 8.0, Disposition Damaged Hardware - this function performs all salvage and/or disposal activities which may result from flight hardware components being damaged or worn out either during the PLS flight or recovery.

Derived Operational Requirements - the following operational requirements were derived from trade studies and analyses. Operational requirements were considered throughout the accomplishment of system concept and optimization trade studies. The requirements would eventually be included in a System Requirements Document. In no special order, these derived requirements include:

- maximum personnel load shall be 10,

- number of launches per year shall be 5 starting in 1996, increasing to 11 by 2020; total flights by the year 2020 will be approximately 220,

- number of dedicated flight vehicle crew members per flight shall be 2, eventually decreasing to zero,

- personnel and personal provisions mass allocation is 300 lbm per person,

- the PLS shall have the capability of berthing at the SSF; active docking shall be considered a backup to a normal SSF controlled berthing,

- reusable elements shall be designed for a life of 50 missions,

- KSC shall be the primary landing location with capability to land at other landing sites or an ocean splashdown,

- the PLS shall be capable of being launched on one of several launch vehicles,

- the PLS shall be capable of transferring to a 270 nmi circular orbit (28.5° inclination) after a launch vehicle delivers it to a 50 x 100 nmi orbit,

- the PLS shall be capable of being launched into any inclination orbit for other missions.

Design for Operations - the advantages of a "Design for Operations" development program are listed in Table 12.1-1. Assuring that the system is designed for operations requires concurrent engineering. A "team" approach to system design with operational requirements receiving an identical emphasis as performance requirements is the essence of concurrent engineering. A "maintenance plan" development exercise similar to that done for commercial and military aircraft can be instrumental in achieving turnaround timeline and life cycle cost objectives.

Flight Support and Ground Operations - for the purpose of this study, the PLS flight support and ground operations functions have been divided into five major categories: manufacturing, operations support, flight support, ground operations, and facilities.

Manufacturing has been included to indicate the close relationship between the final manufacturing operations of element fabrication, final assembly, and acceptance testing and the ultimate operation of the flight vehicle. There is a very close relationship in the commercial aircraft world between the equivalent manufacturing operations and the subsequent aircraft operations. Automatic Test Equipment used at the factory for acceptance testing and the associated test philosophy translates directly to the operator's performance of required operational and functional tests. The methods of fabrication and final assembly can have a significant impact on accessing installed subsystem components.

The direct operational functions have been defined as part of either Flight Support or Ground Operations. While these direct functions normally receive the major emphasis during a system concept study, prudent development of a system with lower life cycle cost requires an equal emphasis on the Operations Support functions. These functions have proven to also be major contributors to the "standing army" associated with the existing space vehicle systems.

Table 12.1-1 Design for Operations

Operations-enhancing vehicle design features	Operational benefits
• Highly reliable onboard systems - Quality components - Redundancy - Fault-tolerant architecture	• Minimize inflight failures, ground controlled inflight reconfigurations, and other contingency operations tasks
• Autonomy	• Minimize operational support burden
• Performance Margins	• Simplify preflight planning analyses and contingency mode data and command preparation • Reduce post flight inspection requirements • Reduce component wear
• Standard interfaces with launch vehicles • Minimum services provides by PLS to service equipment	• Eliminate unique tailoring of onboard software; mission data loads; and ground test and checkout software, hardware, and procedures
• Onboard self-test and vehicle health monitoring system compatible with operations based fault diagnostic and maintenance system	• Simplify test and checkout, flight readiness verification, launch countdown, and post flight maintenance checks
• Modular construction of line replaceable units	• Minimize removal and replacement time for equipment
• Single nontoxic OMS/RCS propellant combination	• Simplify propellant transfer and storage
• Readily available hard point/handling interfaces	• Simplify ground operations, vehicle handling/transfer operations, and support equipment

Operations Support includes items such as logistics, security, base support, and safety. These activities are obvious parts of any industry/government/airline. In addition, hardware/software modifications and the handling of program phase-out would be included under this category.

Flight Support activities do include support during the actual PLS flight, but also include preflight and post flight operations. Crew training, mission planning, and contingency operations (such as in an abort) are covered in this category.

Ground Operations typically involve a significant investment in manpower and include items such as maintenance, integration, launch operations, and recovery operations.

Facilities associated with the PLS include dedicated and shared facilities. Simulators and mockups are examples of dedicated facilities. The launch pad is an example of a shared facility. A spacecraft processing facility may be a dedicated or shared facility depending on the facility requirements of other spacecraft. Other possible facilities that may be required include a software verification laboratory, any manufacturing facilities, a cargo integration facility (depending on the type of launch vehicle), and a recovery site.

A major innovation of this analysis was to determine where, in the flight support and ground operations functions, methodologies currently used in aircraft support and operations could be applied to PLS operations.

A definition of the required facilities, in the true sense of "definition", must be deferred until there is a better understanding of the PLS Operations and/or Maintenance Plans. At this stage of the analysis, it does appear feasible to utilize at least some existing facilities. Further definition of facility and processing equipment requirements is necessary to define specific facility modifications and/or new facility requirements.

• mission model to be provided by NASA,

• launch to a range of inclinations.

Functional Flow - the top level PLS functional flow, Function 0.0, is shown as Figure 12.1-1. This flow forms the basis of subsequent functional flow and timeline analysis. The general physical location of where the specific function is to be performed is indicated. The functional flow contains eight high level flows as follows:

• Function 1.0, Perform PLS Mission Operations - this function performs all normal real-time operations associated with the PLS flight. The function begins with the launch vehicle liftoff and ends with the safe recovery of the PLS flight hardware.

• Function 2.0, Perform Launch Operations - this function performs the necessary operations to transfer the integrated PLS and launch vehicle to the pad and launch. This function begins with the preparation of the pad and ends when liftoff is achieved or the aborted launch vehicle and PLS are returned to the integration facility.

• Function 3.0, Integrate PLS with Launch Vehicle - this function performs the necessary operations to assemble the launch vehicle and PLS into an integrated launch vehicle and to verify satisfactory mechanical and electrical interfaces between all vehicle elements.

• Function 4.0, Recover PLS Flight Hardware and Crew - this function recovers the PLS crew, passengers and PLS flight hardware components. It returns the flight hardware to either a refurbishment facility, or, in the case of damage or wear-out, to a disposal facility.

• Function 5.0, Perform PLS Contingency Flight Operations - this function performs all real time contingency flight operations which may occur between launch vehicle lift-off and PLS recovery.

• Function 6.0, Refurbish PLS Vehicle - this function refurbishes and maintains recovered flight hardware components.

12.2 Flight Support

PLS flight support is based on a premise that the PLS flight can be conducted similar to an aircraft flight. The crew has a degree of autonomy, consistent with the vehicle autonomy, not previously attained for manned space flight. Integral with this premise is an Integrated Operations support concept. The mission planning and control is performed by the same resources. The flight ascent planning is part of the launch vehicle ascent flight planning.

Because of the increased crew autonomy, crew training becomes extremely critical. The design of the PLS will need to provide flight simulators and simulation software to enable the crew member to attain an initial qualification and maintain proficiency - similar to current aircraft and weapons system simulators.

A Central Maintenance Computer (CMC) capable of controlling subsystem operation and recording the status of the components is critical to successful flight support during the preflight, flight, and post flight support operations. This same CMC is critical to rapid turnaround of the flight vehicle during ground maintenance operations and is discussed later in this report.

Pre-planning for contingency operations is critical to the successful execution of any contingency operation. Because of the increased autonomy of the flight system, vehicle, and crew, a Failure Modes and Effects Analysis (FMEA) to include corrective actions must be accomplished prior to PLS activation - similar to the publication of emergency procedures prior to first flight of an airplane. The real time anomaly resolution by a flight support crew will be a minimum. If it is possible to really conduct a perfect FMEA, there will be no requirement for real time anomaly resolution. However, experience dictates that some capability be provided even for the best understood space flight systems.

Autonomous operations as applied to flight support activities has the objective of reducing the ground "Control Center" manning required to support a flight. The vehicle and crew essentially conduct the flight. The ground crew monitors the status of the flight and responds when needed - similar in concept to an airport control tower and FAA control center operation. Data links and a ground maintenance computer compatible with the on-board CMC are required. The ground computer must be capable of accepting any, and perhaps all, of the data in the onboard computer for real

time anomaly resolution. Normally, data telemetry would not be required and only creates more opportunities to increase ground personnel -someone has to read that routine data. The "Control Center" must have available to it, on an "on call" basis, the engineering and technical expertise available to the ground processing team during that phase of the operations. However, the engineering expertise does not "operate" the "Control Center".

This has the effect of limiting the sheer numbers of "system" and/or "subsystem" engineers required to support an operation. They are utilized as engineers solving engineering problems rather than as monitors, controllers, and communicators. Autonomous operations do have an implied requirement to have some "artificial intelligence" (AI) built into the computerized operations. The AI or "expert system" is in the context of having stored in some accessible data base the combined intelligence of many human minds and experiences. In this manner the intelligence or experience base is retained after the individuals who created the intelligence or had the experience have departed, is accessible even though the individual is "on vacation", and can be applied to a real time application because of the speed of computer operations.

The concept of "Integrated Operations" as applicable to the operation of space vehicles was developed during the initial phases of the Advanced Launch System studies. It is the centralization of the sustaining engineering, planning, control, coordination, and execution of all activities preparatory to a launch, during the flight of the vehicle and following the successful recovery of the flight vehicle and is summarized as Figure 12.2-1. It is enabled by the utilization of existing information processing/handling technology. It was an attempt to counteract the perceived fragmentation of the responsibility for successful operations into separated "centers of control" with all the inherent bureaucracy. It works in an environment of "networked" computerized information flow, of "teamed" technical, engineering and managerial talents, and of "consolidated" operational functions. The PLS with its specialized mission role and its limited operating locations is an excellent candidate for this concept. Applying operational concepts applicable to a world-wide civil or military system, capable of operating from many operating locations, in a pre-computerized information flow environment to the PLS is a mistake. The "overhead" will stifle the operation of the system.

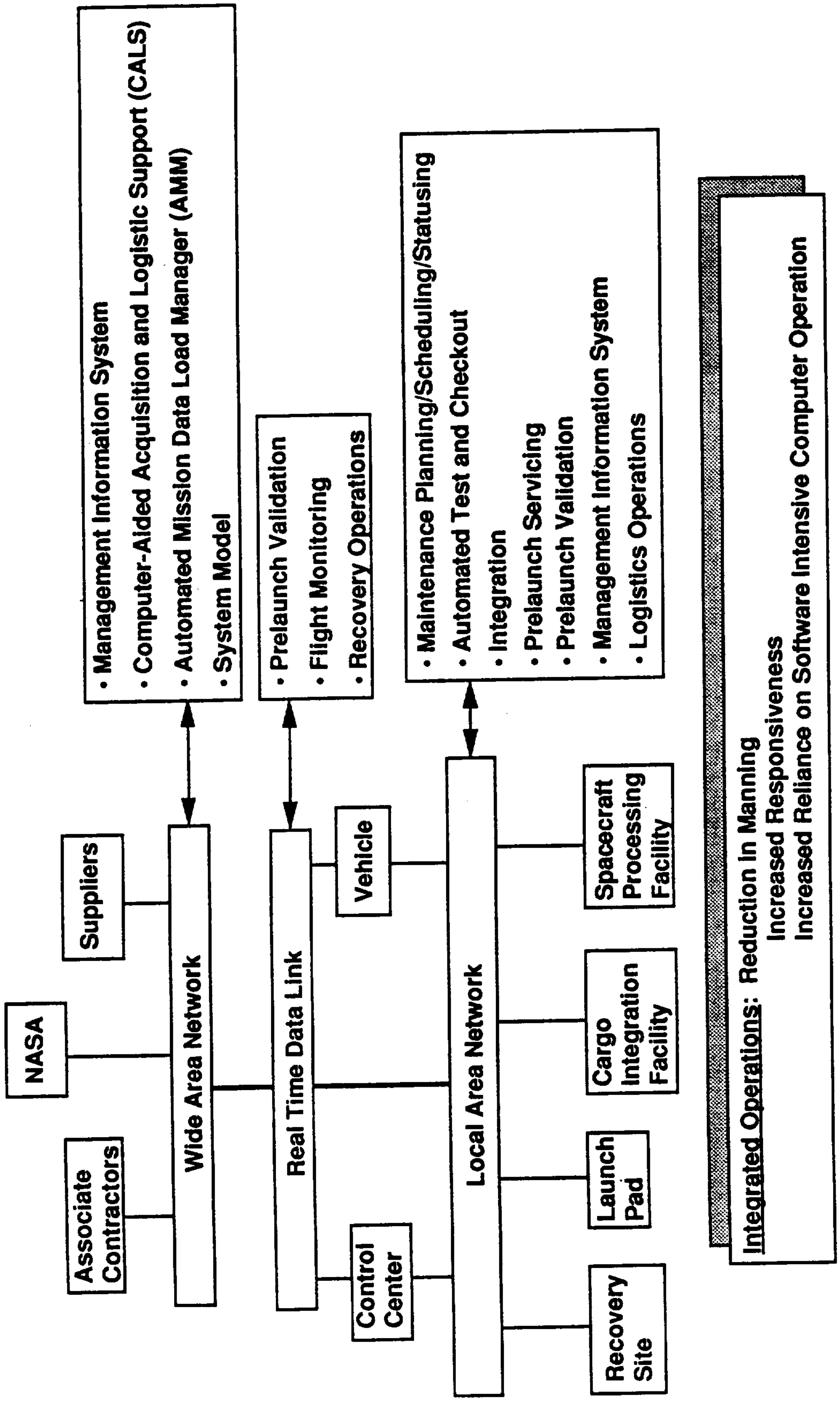


Figure 12.2-1 Integrated Ground Operations

Enhancing the Integrated Operations concept are such things as:

- Computer-Aided Acquisition and Logistic Support (CALS),
- a computerized "simulator" or "system model" capable of supporting technical and managerial decision making, and,
- a computerized mission planning tool similar to the Advanced Launch System's Advanced Development Plan item "Automated Mission Data Load Manager (AMM)".

Some perceived advantages of Integrated Operations are:

- a reduction in overall program manning (reduce the "standing army"),
- an increased responsiveness to changing mission parameters, surge scenarios, and contingency operations,and,
- a reduction in facility and equipment acquisition and maintenance costs.

Possible disadvantages of Integrated Operations could be:

- increased software development and maintenance costs, and,
- increased reliance on a software, computer intensive system operation and management organization.

One of the facets of Mission Analysis accomplished during this study was to identify various issues which remained to be addressed when more details become available. Function 1.0 Perform PLS Mission Operations, was analyzed to a detail which allowed this to be done (see Figure 12.2-2). The relatively simplified level 2 and selected level 3 functional flows that were developed to accomplish the task are shown. The level 3 tasks developed included:

1.2 Perform Orbit Operations Approaching SSF, see Figure 12.2-3,

1.3 Perform Wait Activity at SSF, refer to Figure 12.2-4,

1.4 Perform Orbit Operations Departing SSF, (Figure 12.2-5), and,

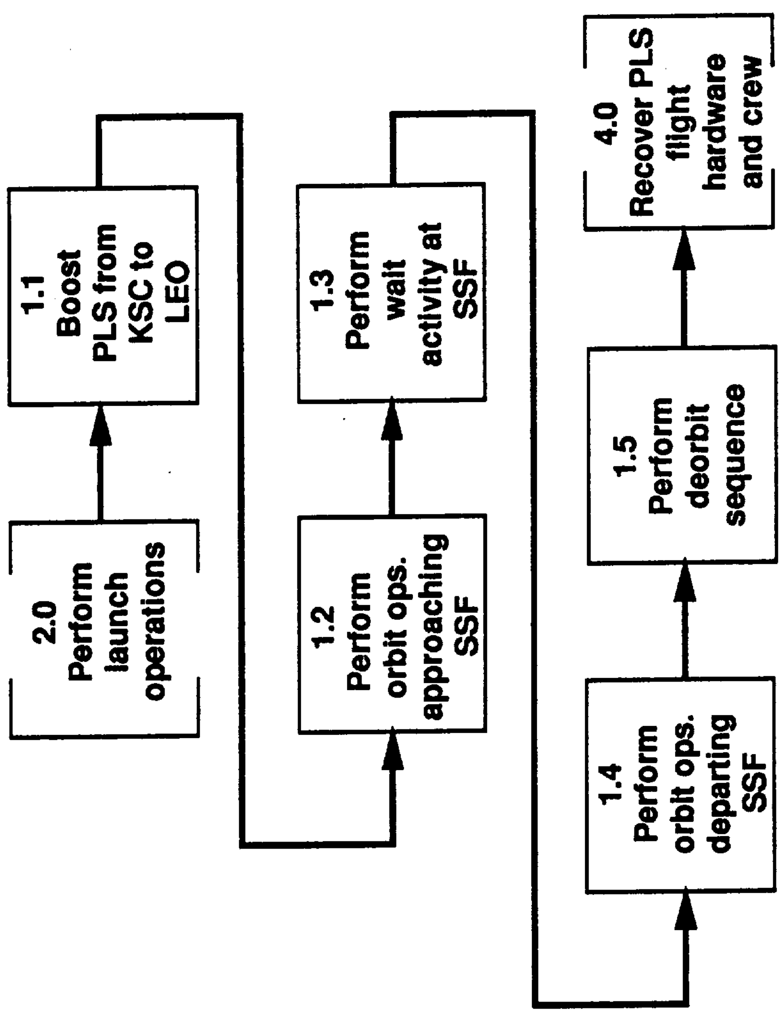
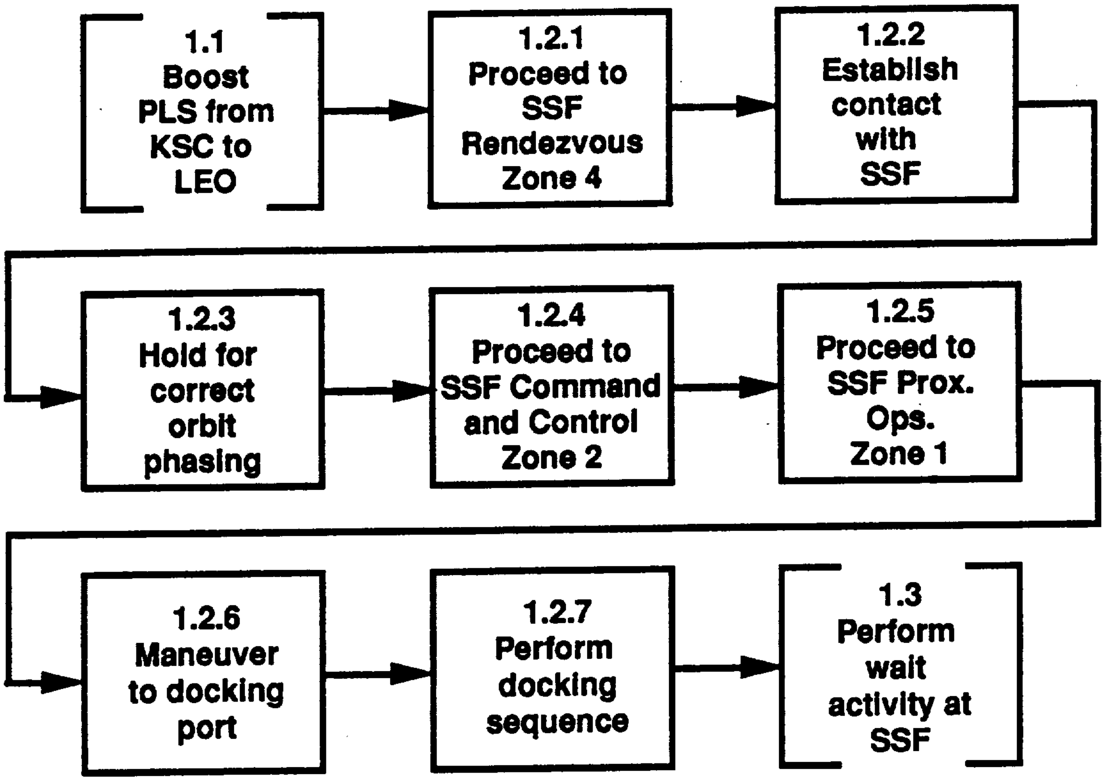


Figure 12.2-2 Level 2 Functional Flow - 1.0



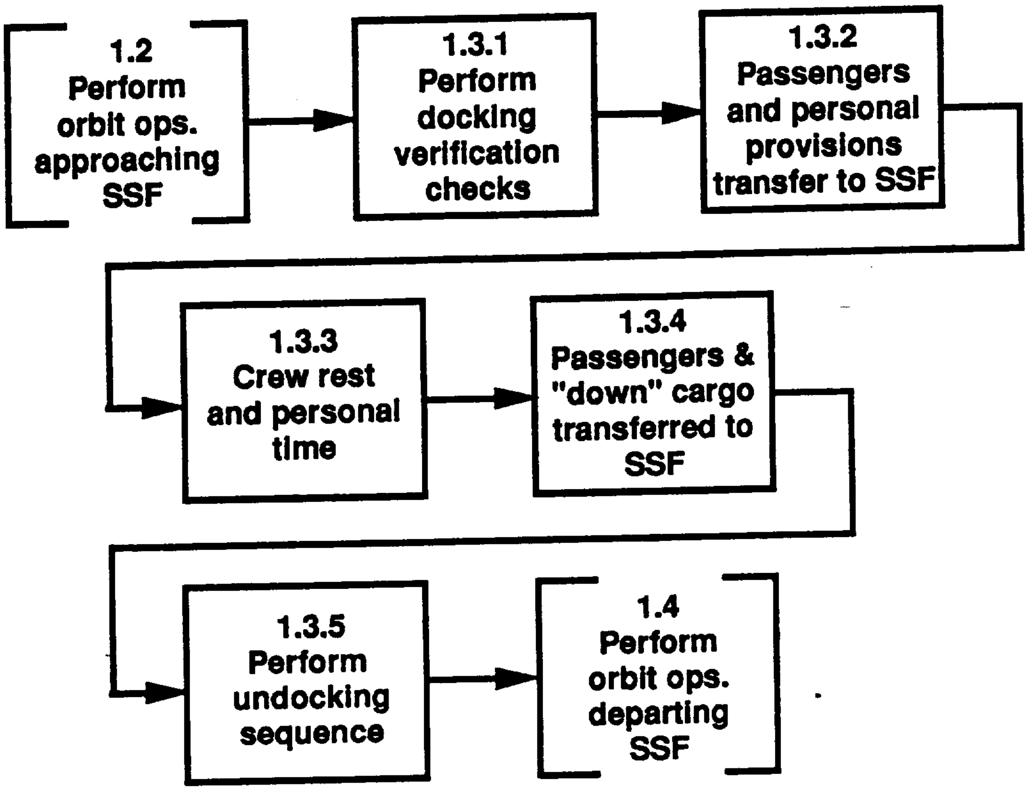
Description:

- PLS enter SSF Rendezvous Zone, also known as Zone 4, co-orbit behind SSF between 37 km and 185 km
- PLS proceeds to SSF Command and Control Zone (Zone 2), co-orbit behind SSF up to 37 km
- PLS enters Zone 1 (Proximity Operations Zone), or within a 1 km sphere around SSF
- PLS maneuvers with cold gas thrusters to a point where, nominally, the SSF RMRS would grapple the vehicle and position the PLS on a docking port
- Typically 8 - 12 hours duration in this phase

Issues to be addressed in the future:

- Approach flight profile
  - Active vehicle (PLS) must have sun outside 20° line-of-sight
  - Preferred and back-up docking locations on SSF
- SSF environment considerations
  - Active vehicle (PLS) shall minimize wake impingement
  - Contamination
  - Shadowing

Figure 12.2-3 Level 3 Functional Flow - 1.2



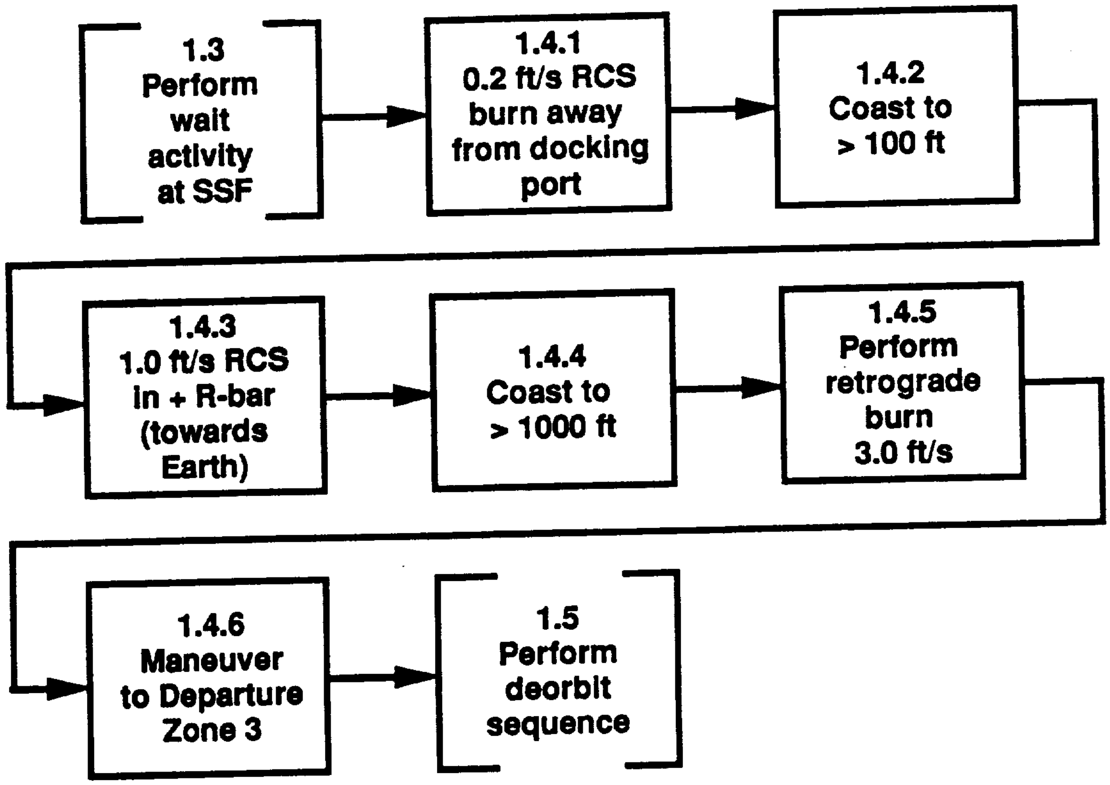
Description:

- PLS post dock checks and safing sequence
- Passengers exchange at SSF
- Typically a minimum of 12 hours duration in this phase

Issues to be addressed in the future:

- SSF services available
- PLS environmental pollution
- Degree of health monitoring
- Level of system shutdown while docked

Figure 12.2-4 Level 3 Functional Flow - 1.3



Description:

- Separation "burn" of 0.2 ft/s away from SSF using cold gas system – coast to at least 100 ft away from SSF
- Separation "burn" of 1.0 ft/s in + R-bar direction using cold gas system – coast to at least 1000 ft away from SSF
- Separation "burn" of 3.0 ft/s using RCS – coast to Departure Zone 3
- Co-orbit in front of SSF between 37 km and 185 km
- Typically 8 - 12 hours duration in this phase

Issues to be addressed in the future:

- Departure flight profile
  - Active vehicle (PLS) must have sun outside 20° line-of-sight
- SSF environment considerations
  - Active vehicle (PLS) shall minimize wake impingement
  - Contamination
  - Shadowing
- Last minute alternative landing site selection

Figure 12.2-5 Level 3 Functional Flow - 1.4

1.5 Perform Deorbit Sequence, see Figure 12.2-6.

A brief description of each level 3 function, the approximate duration of the function, and the "Issues to be Addressed" are as indicated on the Figures. Note that a functional flow was not developed for 1.1 Boost PLS from KSC to LEO, because that function is entirely dependent on the boosting launch vehicle.

12.3 Ground Operations

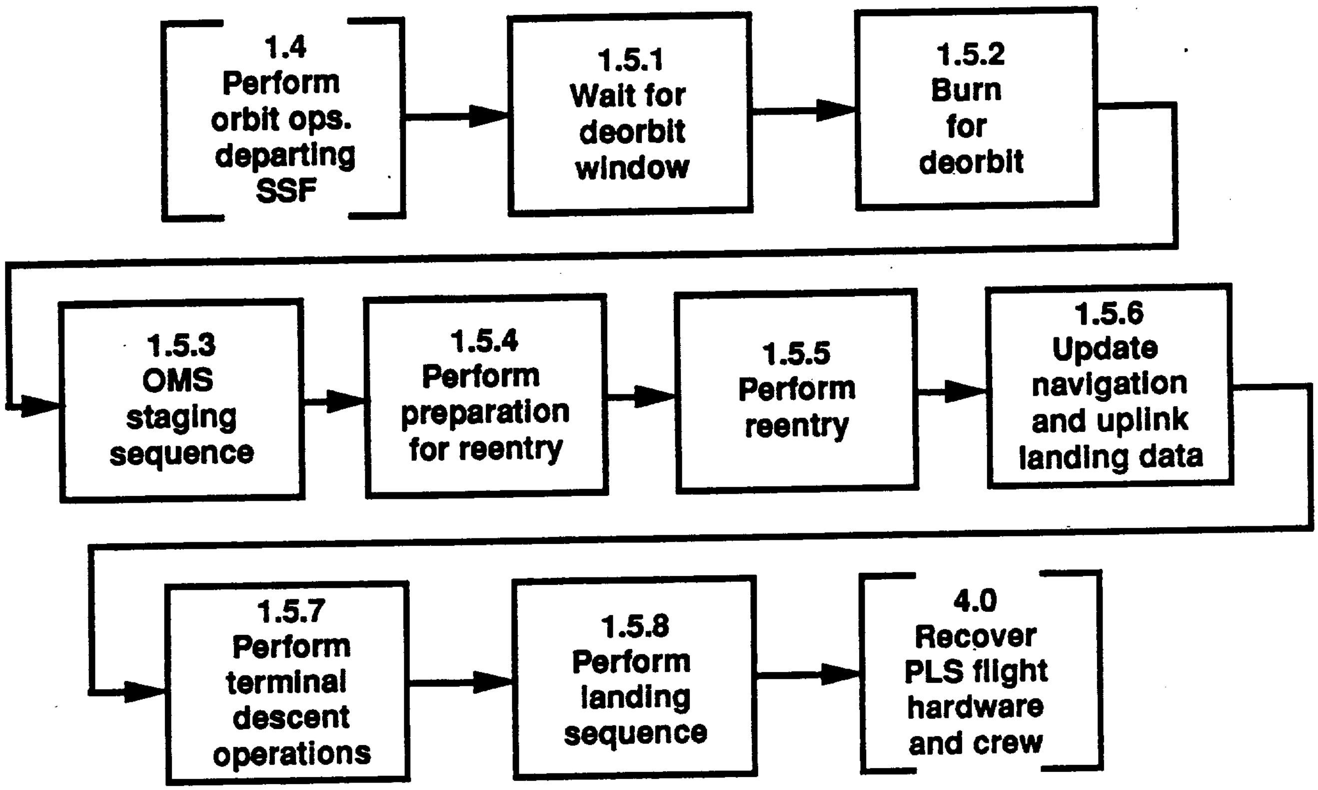
The ground operations functions studied include maintenance, integration, launch operations, and recovery. Particular emphasis was placed on the recovery and maintenance functions and the resulting vehicle turnaround implications. The functions were analyzed to ascertain the applicability of operating the PLS on the ground similar to operating an aircraft on the ground. Critical to attaining a turnaround operation similar to aircraft operations are automated test and checkout and an autonomous vehicle design with a minimum of external interfaces to verify. The CMC, so critical to autonomous flight operations, is a "key player" to a successful turnaround operation.

Maintenance operations include inspections, scheduled and unscheduled maintenance, and refurbishment. Pre-flight verification and checkout and consumables loading is also included as part of these operations.

Integration includes items such as interface verification, services, access procedures, and closeout activities.

Launch Operations are concerned with the prelaunch verifications, hazardous operations (such as fueling), and crew ingress activities that typically happen immediately before a flight.

Finally, Recovery operations involve the securing and safing of the vehicle after a land or water landing, the offloading of crew and "cargo", and the transportation of the vehicle back to the refurbishment site.



Description:

- Wait for reentry window
- Initiate reentry burn (OMS burn, jettison OMS/radiator module, RCS separation burn, update navigation, re-orient vehicle)
- Reentry (GN&C functions, update landing site conditions)
- Deploy recovery system (Drogue chute @ M1.5, parafoil subsonic)
- Land at KSC
- Typically less than 3 hours duration in this phase

Issues to be addressed in the future:

- Range safety/overflight
- Backup recovery system
- Communications links/blackout

Figure 12.2-6 Level 3 Functional Flow - 1.5

The PLS ground processing consists of the four functions of:

4.0 Recover Flight Hardware and Crew,

6.0 Refurbish PLS Vehicle,

3.0 Integrate PLS with Launch Vehicle, and,

2.0 Perform Launch Operations.

The accomplishment of these functions results in "turnaround" operations. The turnaround timeline is defined as the elapsed time between the "landing" of a PLS flight vehicle and the "liftoff" of the launch vehicle which carries that vehicle on its next flight. The timeline requirement affects and is affected by design of the PLS vehicle, the traffic model and desired interval between flights, PLS work schedules and manpower availability, characteristics of the launch vehicle ground processing, and the PLS operational fleet size.

For the purpose of timeline analysis the functions of "recovery" and "refurbishment" are combined into one function.

The objectives of PLS turnaround operations are:

- minimize time between flights,
- simplify operations to attain maximum flexibility,
- minimize operations costs
- attain perfect abort
- maximize surge capability, and,
- overcome "standing army" problem.

The objectives are somewhat at odds with each other. A compromise would have to be arrived at that balances the benefits of each of these objectives. Some comments on the objectives as they exist at this stage of conceptual design:

- Minimizing time between successive flights is a noble objective which should contribute to minimizing costs and maximizing flexibility. However; it may well be self defeating if in shortening the time required to ready the vehicle for the next flight, excessive development and operational costs (including overtime) are incurred. The mission model requirements must also be considered. To minimize the processing timeline merely to have the vehicle "standby" waiting for its next flight may not be effective.

- Simplifying the processing operations will not only maximize flexibility, but it will undoubtedly result inlower operational costs and improve the capability of the system to surge.

- "Surge" has not been well defined for the PLS; however, there will certainly be some. A capability to rapidly respond to emergencies involving people at SpaceStation Freedom is a type of "Surge" requirement.

An approach to attaining quick turnaround is to design the aerospace system similar to a commercial aircraft system. Related technologies are transferred from the commercial aircraft system design and adapted to the PLS design. This approach requires the engineering of the vehicle maintenance process and procedures concurrent with vehicle design and the incorporation of the design characteristics listed:

- include adequate design margins to assure parameters are well within operational characteristics,

- designs should be modular, redundant, accessible, reliable, fault tolerant, and feature integral health monitoring provisions,

- develop the ability to complete a flight with a Minimum Equipment List (MEL),

- minimize hazardous materials, and
- utilize automated test and checkout technology (on-board BIT/BITE) and make sure compatible ground diagnostic and maintenance systems are in place.

Again, the ultimate system design which supports or even allows a quick turnaround will only result from planning and designing for it.

The automated test and checkout concept proposed for the PLS parallels current factory Production Functional Testing applicable to commercial airplanes exiting the production line (see Figure 12.3-1). The concept utilizes Automated Test Equipment capable of being operated by technicians requiring a minimum of engineering skills. The actual test is performed locally with limited requirement for remote consoles and a myriad of data links from various test stations. The test parameters and procedures reside in a data base in a Control Center and are "called up" by the test equipment as required. The technician initiates the test, notes "pass" or "fail", and "fixes" any failed subsystems in accordance with predeveloped procedures. Engineering support is required only when there is a "fail" indication and the test equipment does not isolate the failure or the data base does not include the "fix" procedure.

In addition to the automation, there is some processing philosophies integral to the concept. These include:

- A "traveling team" stays with a vehicle throughout the processing. The size and membership of the team may vary as different skills are required, but a cadre of people intimately familiar with the requirements for and status of the specific vehicle processing follow the vehicle from recovery to launch. This also tends to result in a less tangible benefit of creating "ownership" of the vehicle, resulting in better quality work.
- Repetitive testing is kept to a minimum. Only that subsystem functional testing necessary to verify an interface will be performed during the integration function.

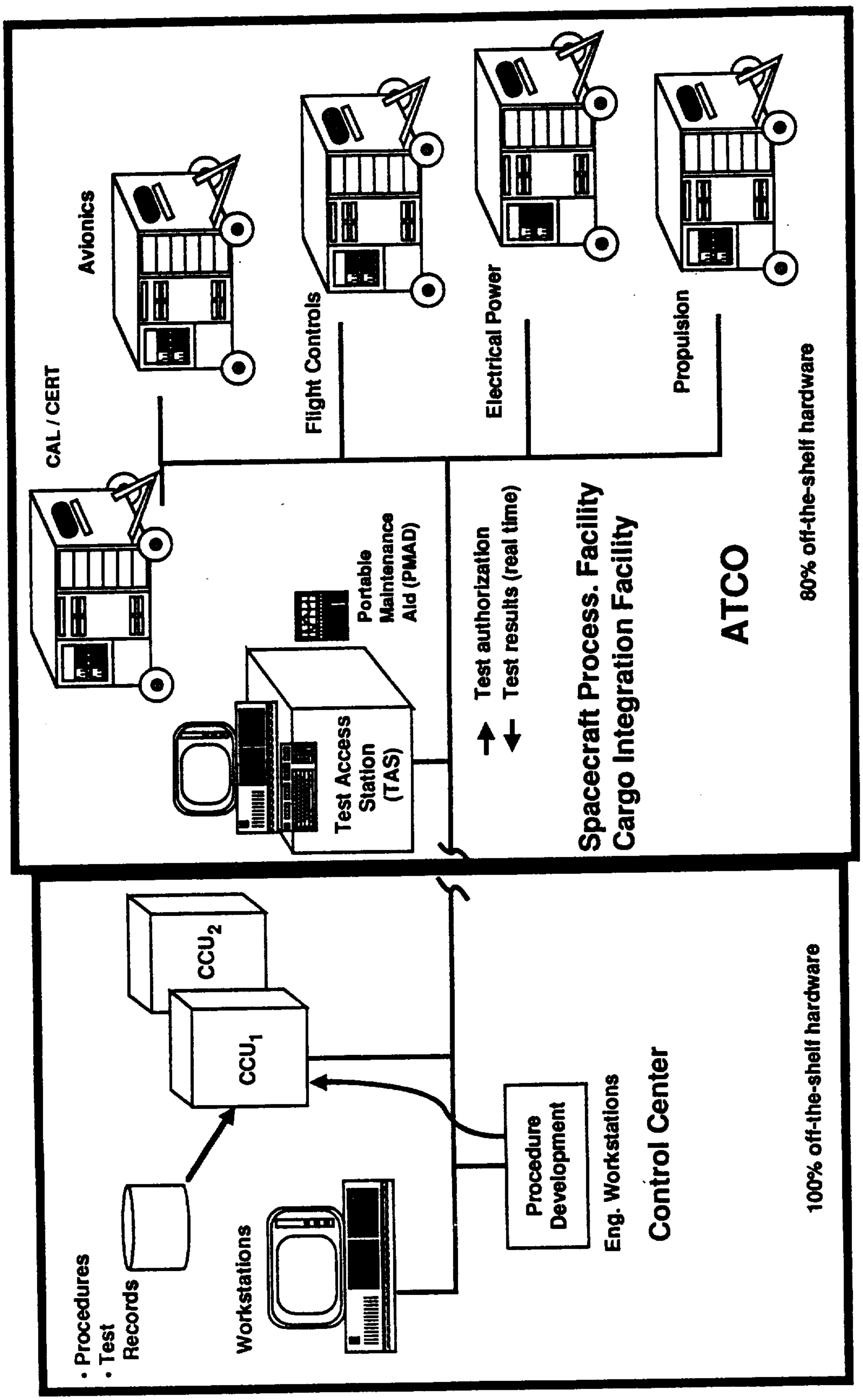


Figure 12.3-1 Automated Test and Checkout Concept as Used With Commercial Airplanes

- Management functions are performed from a single point in the Control Center. Responsibility for the successful turnaround is centralized with well defined roles and responsibilities.

Due to the intrinsic hazardous nature of Launch Operations, tests performed after integration with the launch vehicle prior to rollout and at the launch pad are performed from the Control Center. This facet of the concept is consistent with the processing philosophies. It is necessitated only because of a requirement to physically locate the "team" remote from the launch pad - particularly during launch.

A related technology which should transfer to any advanced space transportation system, including the PLS, is the Boeing 747-400 "Integrated Electronics On-Board and Ground Failure Diagnostic and Maintenance System". The major components are briefly described as follows:

- Engine Indicating & Crew Alerting System (EICAS) - the sensors and interface units which monitor engine performance and condition and indicate failures, faults, and out of tolerance conditions to the flight crew.

- Central Maintenance Computer System (CMCS) - a centralized location for access to maintenance data from all major avionic, electrical, and electromechanical systems on-board the aircraft.

- Integrated Display System (IDS) - displays flight, navigation, and engine information.

- Fault Reporting Manual (FRM) - a book carried on board the aircraft which allows the flight crew to "decode" on-board data to report a problem to the ground. The system does have the capability, not necessarily installed on every aircraft, to report problems via data links directly from the on-board computers to ground computers.

- Fault Isolation Manual (FIM) - a book used by the ground crew to isolate and repair indicated failures, faults and out of tolerance conditions - a "trouble shooting" guide in case the anomaly cannot be isolated by the on-board built-in-test equipment.

The system configuration is very flexible and not all aircraft have the same features (option of the aircraft user). It can be very automated with the on-board CMC "forwarding" maintenance data to a ground station computer. The data is then used by the ground crew to prepare for required corrective maintenance actions (such as obtaining spare parts, positioning the required ground equipment and/or assigning the correct maintenance personnel).

This technology exists and is used by commercial airlines to make their operation more cost effective. It should be evaluated for applicability to the PLS.

The processing operations include recovery and maintenance and commence immediately after either a normal, non-normal, or abort flight scenario. The processing scenario and transportation methods vary with each flight scenario. Additional processing results from any flight scenario other than normal operations.

The processing scenario associated with a normal flight involves ground transportation after a land landing at KSC. Landing the PLS at any site other than the primary landing site requires additional airlift transportation. A secondary site may have the required GSE in place; however, this is highly unlikely unless the specific site was utilized quite often. Landing at a contingency airstrip would assuredly require the airlift of any required GSE. After the PLS is safed and deserviced it may require transportation to the factory for refurbishment, if damage occured in the non-normal landing, and from there to KSC for maintenance and servicing for the next flight.

Abort operations resulting from an emergency either on the launch pad or during launch immediately after liftoff will result in the PLS landing in the water (splashdown). Such a landing will require a recovery ship. Aborts occurring after the launch vehicle has reached 300,000 feet can result in either a water splashdown, a landing at KSC, or a landing at either a secondary site or contingency airstrip. Possible secondary landing sites are discussed as Table 5.2.1-1. In any case, additional transportation activity and requirements for transporters will result. In addition, if the vehicle is recoverable and repairable/refurbishable, there will be additional unscheduled maintenance activities (such as cleaning off salt water residue).

The total turnaround time for all processing scenarios remains a subject for future study. It is highly dependant on and will affect the ultimate vehicle design.

Analysis of the refurbishment function is a study in itself. It requires a knowledge and definition of the hardware and software to be operated which is not available at this time. Integral to the development of the hardware and software is the development of a maintenance plan. At this time, only an approach and a general maintenance philosophy can be stated.

First, the approach to maintenance and/or refurbishment will vary depending on whether the PLS is recovered on land or in the water. A water landing will probably require more "refurbishment" than a land landing assuming the same vehicle design.

Second, the system and subsystems should be designed to be as maintenance-free as practical: minimum recurring inspections, minimum between flight functional and operational checks, and minimum components which must be removed and replaced after every flight. There will assuredly be required activities of each type. At this stage, the approach must be to "minimize" as much as practical.

Third; the system, launch vehicle and its subsystems, will probably require some type of recertification prior to a subsequent flight. The recertification process should be kept as simple as possible. For comarison commercial aircraft conduct a "transit check" between flights and a "daily" inspection every 24 hours that essentially constitute a recertification.

Subsystems which are candidates for refurbishment and a brief description of what that refurbishment might be are listed as Table 12.3-1. The subsystem design will determine the extent of refurbishment required and the effort that will be required to complete it.

The proposed general maintenance philosophy for the PLS is a slight modification of the existing standard Air Force three level aircraft maintenance concept. At the "organizational level", Line Replaceable Units (LRUs) are removed and replaced as required. "Intermediate level" maintenance would apply only to selected items of equipment - exact items would be determined during a Maintenance Plan development exercise. All maintenance beyond the removal and replacement of LRUs and any refurbishment is proposed to be performed at a "depot level" - in the case of the PLS, at the factory.

Table 12.3-1 Typical Refurbishment Operations for Subsystems

Subsystem	Maintenance Actions
- Structures	Inspect for damage; verify integrity of seals, fasteners and mechanisms
- Thermal protection	Replace missing or damaged tile; service and functionally verify active systems
- Propulsion	Verify controller ellectronics; verify integrity of the system (leak check); inspect for failed or failing high speed turbine components; remove and replace failed components
- Power	Service fuel cell reactant supply; verify controller electronics; inspect, service, and lubricate rotating machinery
- Avionics	Verify electronics via BIT/BITE; remove and replace failed components
- ECLSS	Service/recharge fluid systems; verify systems integrity (leak checks) and functionality; remove and replace expended items (filters) and failed components
- Recovery/landing	Remove and replace expended hardware (parachutes and pyrotechnics); verify systems functionality; verify installation of replaced expendables

The logistics support concept is to integrate the logistics and the operations functions into the "Integrated Operations" concept. Because of the relative uniqueness of the PLS and the program's relative small size, it would probably be very inefficient to establish separate operations and logistics support organizations. The proposed concept (see Figure 12.3-2) integrates the organizations and shares facilities, equipment and manpower resources. The result is a more efficient total operations which is responsive to the mission(s) assigned.

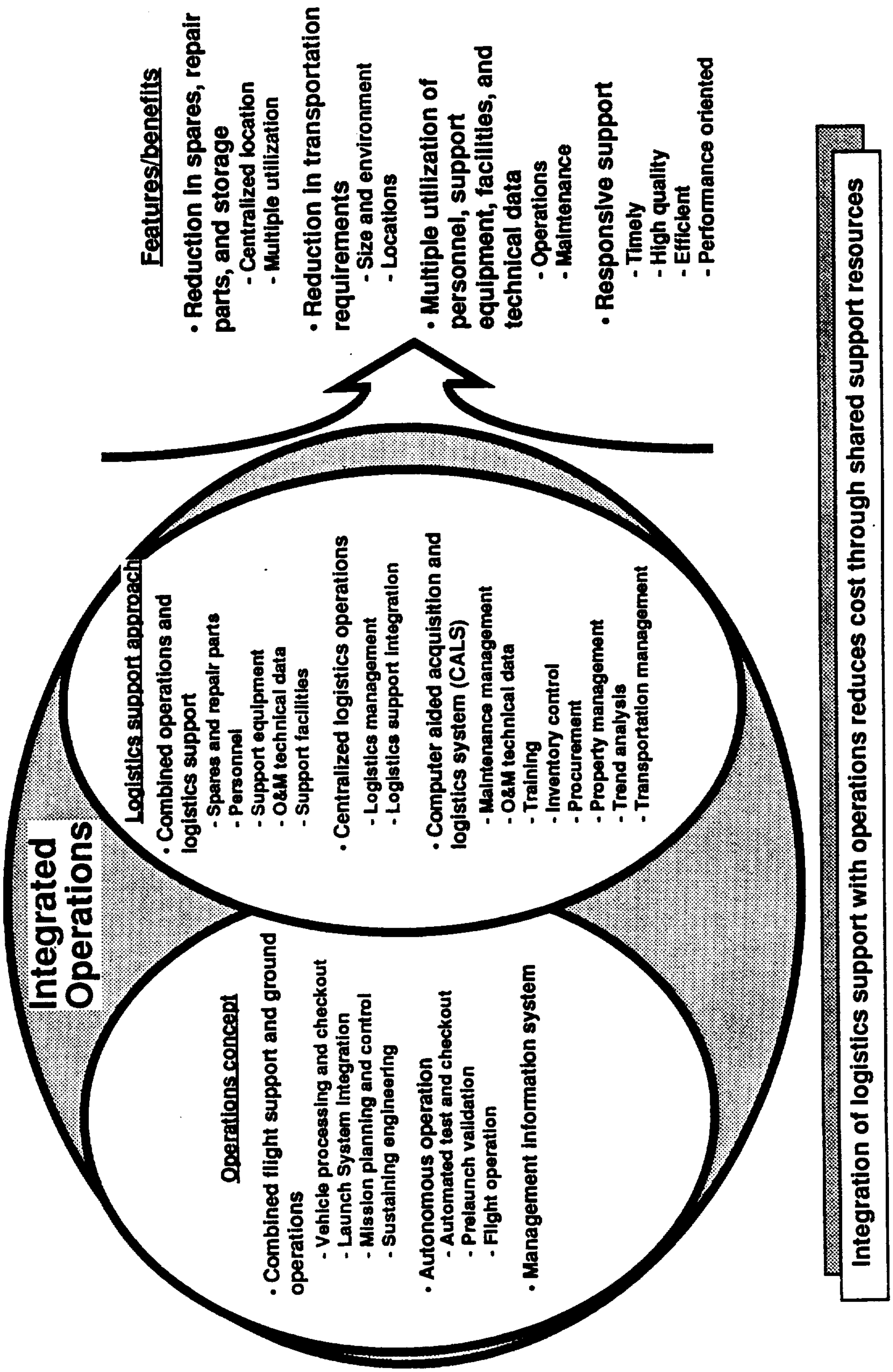


Figure 12.3-2 Overall Logistics Support Concept

13 PROGRAM DEVELOPMENT PLANNING

The task identified as Task 2j was to define a PLS program plan which was to include: design and development, manufacturing, ground and flight testing, and, a strategy for the transition from prototype to routine operations. Table 13.0-1 identifies each of these areas of preliminary analysis as they apply to each phase of the PLS Program. Coordination with the Space Shuttle, Space Station Freedom (SSF), and the future Advanced Launch System (ALS) booster family is also addressed.

13.1 Approach

The first task was to review information from the NASA Space Transportation System (STS) Orbiter and other space programs such as the Inertial Upper Stage, Dynasoar, ACRV, and Space Station Freedom was completed. Commercial programs like the 747 and 737 were also investigated to determine development planning methods for a civil air transportation system which operates with quick turn-around times and a relatively small maintenance crew. A review of these two ends of the development program spectrum enabled the identification of the driving requirements which have tended to impact the development timing, money, and technology applications in most aerospace programs in the last two decades.

13.2 Groundrules and Assumptions

The work breakdown structure (WBS) was supplied by NASA. All technology applications were targeted for a 1992 maturity point in time. Table 13.2-1 provides a list of the final groundrules used to develop schedule and cost data.

The mission model provided by NASA and the SSF crew size forecasts were used to establish passenger levels, flight rates by year, and first operational flight year requirements. These groundrules and assumptions were used to initially set the start and stop dates for a Phase B and C/D development plan which would meet the needs of the projected transportation system demand. Table 13.2-2 provides the list of primary missions established as a baseline to be used for evaluation and planning. These schedule data, along with a the conceptual design of a biconic vehicle, formed the basis for the point of departure development plan in the Boeing study. The final PLS master schedule is provided in Figure 13.2-1.

Table 13.0-1 Development Plan Elements

	Phase B	Phase C/D	Phase E/F
• Design & Development	Develop outline plan	Update existing schedule and groundrules	Breakout tier 2 elements
• Manufacturing	Hardware Demo.'s	TFU#1 Flow; FSD test philosophy	Lot Buy Plan
• Ground & Flight Testing	Outline	Expand flt. test description	Define KSC support
• Test to Operations Transition	Interface Issues	***Transition philosophy;*** Interface tests(?)	
• Program Coordination	Interface Issues	Flight test req.	Build rates

C-5

Table 13.2-1 PLS Program Plan Groundrules

- System design is revised to a LOX-RP vehicle with new Orbital Maneuvering System (OMS) thruster development.
- Test quantities have been revised to include new hardware.
- No change in Phase B or C/D start dates.
- Four flight tests: 2 unpiloted; 2 piloted (no change.)
- New launch escape system design: Integrated LOX-RP "pusher" design using modified RS-27 engine.
- Crew rotation and Lunar/Mars personnel delivery to Space Station Freedom (SSF) are the primary and secondary PLS missions.
- Desired initial operating capability met by FY 1999.
- Ground control software development is not addressed.

Table13.2-2 Primary Missions for Evaluation

Personnel Size:	10	10		(TEST FLTS)
Flight Mission:	**Station**	**Lunar/Mars**	**Total**	
1996 GROUND TESTING			0	
1997 QUAL. TESTING			0	
1998 FACILITIES SETUP			0	
1999 UMANNED FLT TEST			0	(2) Unmanned
2000	1	0	1 +	(2) Manned
2001	2	0	2	
2002	3	0	3	
2003	4	2	6	
2004	5	2	7	
2005	5	2	7	
2006	6	2	8	
2007	6	2	8	
2008	6	2	8	
2009	6	2	8	
2010	6	2	8	
2011-2019	(SAME RATES PER YEAR AS 2010)		72	(8/Yr.)
2020	6	2	8	
Total	110	36	146 +	(4) First Times
Average	4.4	2.0		

* Boeing has not included the satellite service units in the final planning until better ops. definition is available

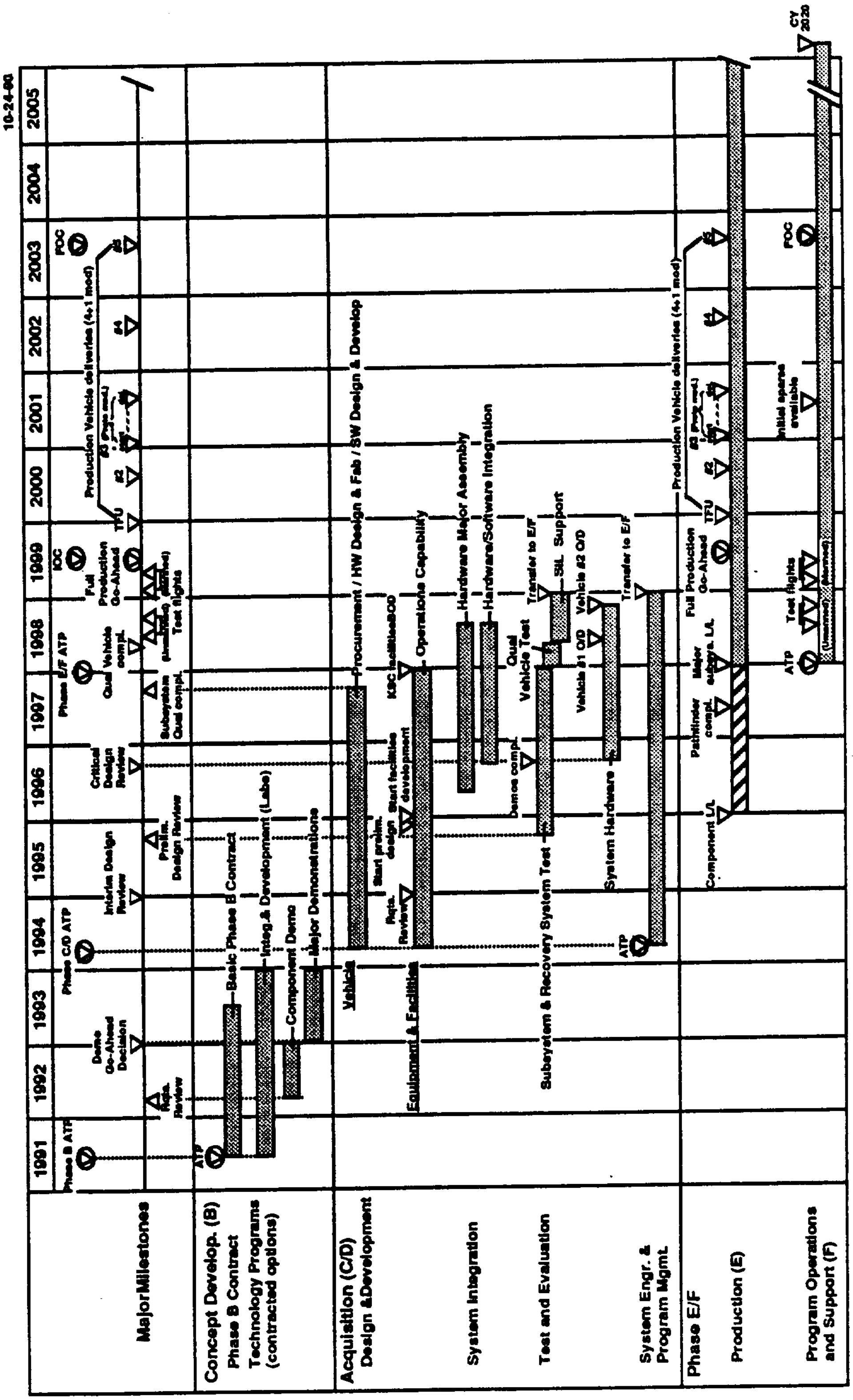


Figure 13.2-1 PLS Master Schedule

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Additional development requirements were derived from several technical interchange meetings with the JSC program office and other NASA center personnel. Software development requirements were established for avionics development, vehicle flight software, and the software development facility. Training, KSC operations, and mission control facilities development assumptions were established from the same technical meetings with NASA technical personnel.

Mission needs were groundruled for the PLS vehicle. The primary mission need is for the PLS to provide crew rotation transportation service from Earth to Space Station Freedom. Secondary missions include satellite servicing and other low Earth orbit missions. The development planning was primarily driven by the crew rotation configuration requirements and by kits for satellite servicing needs (scenario for satellite servicing is still incomplete). Mission need assumptions and preliminary vehicle design concepts influence the development plan and test planning concepts.

13.3 Design and Development

Each major task and activity to be accomplished during Phase B is shown in Table 13.3-1. Specific areas of research and development are identified for each task as well as the estimated, required resources. Figure 13.3-1 provides the final PLS Phase C/D schedule which includes procurement, hardware, assembly, hardware/software integration, and test.

13.4 Test and Evaluation

Using the PLS Master Schedule (Figure 13.2-2) as a baseline, a final "Test and Evaluation" plan was developed for Phase C/D. Figure 13.4-1 provides the overall schedule for the development of specific test articles required to accomplish a successful ground test program leading to the first PLS flight test vehicle in mid 1999.

A summary matrix was created (Table 13.4-1) to identify the major test/simulator articles needed to accomplish specific functions for each test (ground and flight). Both primary and secondary use is indicated for each article which may not be apparent on the schedule. It should be noted that the specifications for each test/simulation article are driven by it's primary use. Section 13.4.2 provides the rationale for pricing of pre-flight articles, vehicles, and tests from which Table 13.4-1 was developed.

Table 13.3-1 PLS Phase B Plan

(30 Month Phase B Length) Phase B Development Task	Areas of PLS Research & Dev.	Estimated Resources	
Facilities & Integration	Contractor/JSC/KSC	60	Manmonths
Structures,Loads, Dynamics	Config. Design & Kits	150	
Thermal Protection & ACC	Adv. Reradiative Mtl., Coatings, ACC Flap	120	(+ Mtl.)
Aerodynamics Engineering	Body Shape, Thermal, Reentry Modeling, Abort/Failure Eval.	90	
Mass Properties & Perform.	Optimize Subsystems	60	
Propulsion Rqmt.'s & Demo.	New OMS, RS-27 Mod.	60	(+ Subc.)
Electrical Power Demo.'s	Fuel Cells, Distr. Hdw.	60	(+ Equip.)
Avionics Technologies	6 DOF Sim., VHMS , Man-in-Loop Demo.'s	120	(+ Equip.)
Software Rqmt.'s & Demo.'s	Flight & PSE Arch.	150	(+ Subc.)
Life Support & Environ. Ctl.	HE Fluids, VHMS	30	(+ Equip.)
Landing & Recovery	Parafoil, Gear Demo.'s	60	(+ Subc.)
Test Plan, Long Lead, Tooling	Operations Plans	120	
System Engr, Programmatics	Plans, LCC, Safety, ILS	120	(+ Data)
Total Estimated Effort -		1,200	Manmonths

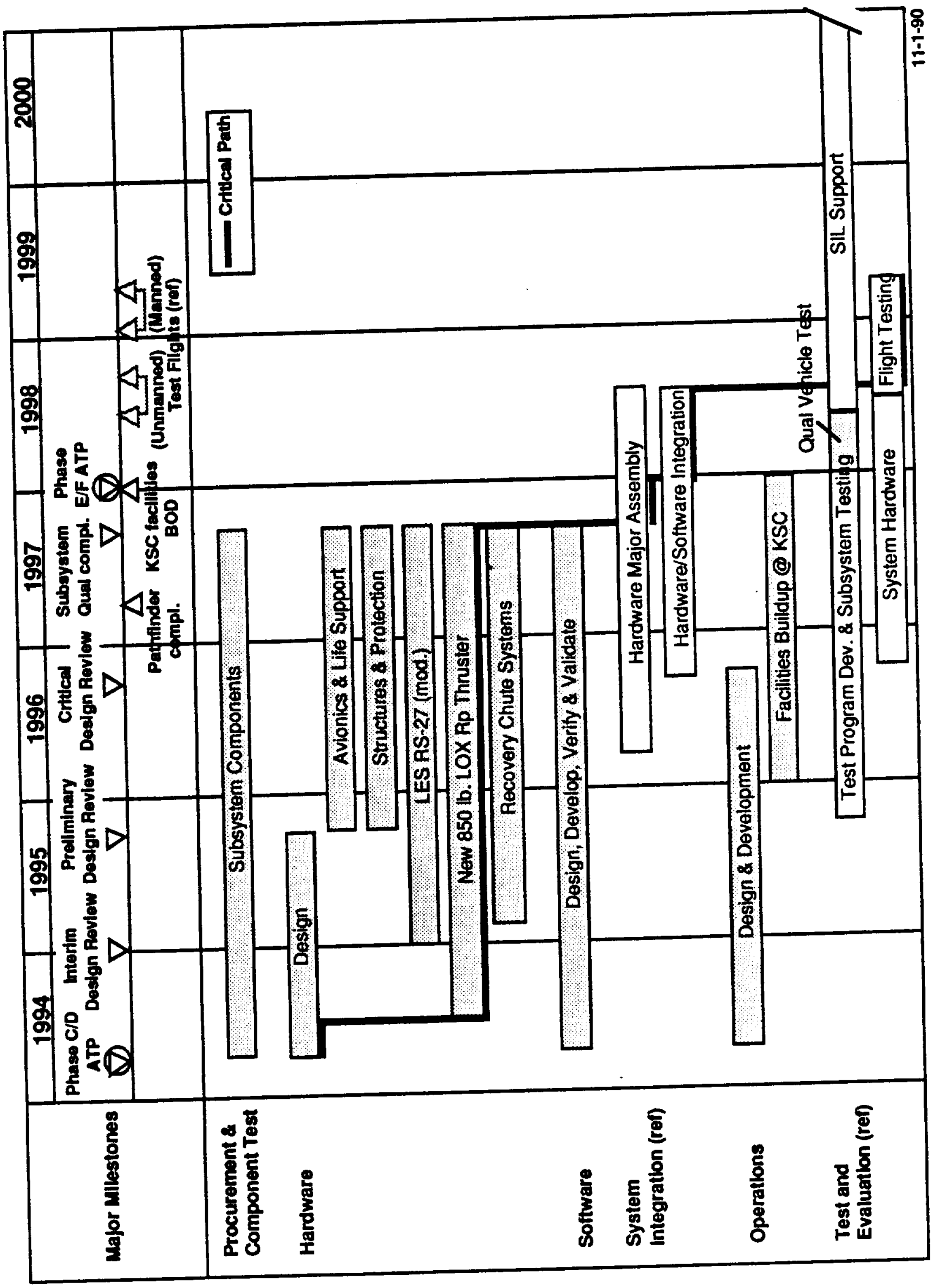

Figure 13.3-1 PLS Phase C/D Schedule

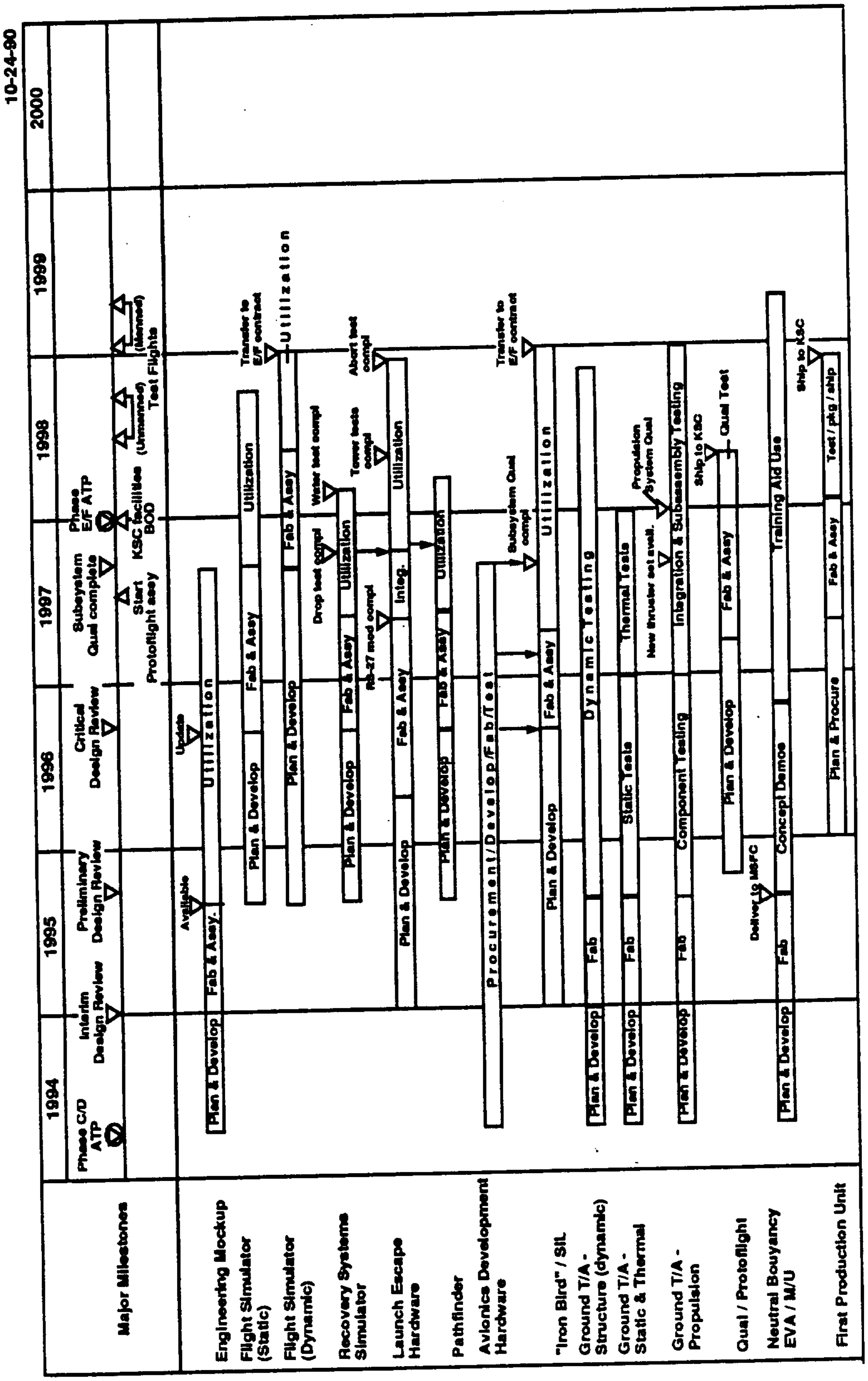

Figure 13.4-1. PLS Test and Evaluation Schedule

Table 13.4-1 Test/Simulator Article Use Matrix

Article: / Function:	Structures tests/ loads verification	Thermal tests/ loads verification	Propulsion tests	Power systems tests	Avionics/C&D test/ verification/development	LSS tests	Impact attenuation tests/ stabilization/floatation	Access verification	IRD development	LES tests	Ground handling/recovery procedures development	Ergonometrics/ human factors	Procedures development	Crew training	Passenger training	Public relations
I. Engineering Mockups			○		○	○	○	●	●	○	○	●	○	○	●	●
IIa. Flight Simulator - Static					●							●	○	●	○	
IIb. Flight Simulator - Dynamic			○		●					○	●	●	●	●	○	
III. Recovery Systems Simulator	○				●		●		○		○		○			
IV. "Iron Bird"/SIL		○		●	●	●			●				○			
V. Launch Escape Simulator	○		●						○	●	○		○			
VI. Neutral Bouyancy/EVA M/U								○				○	●	●		
VIIa. Ground TA - Structure	●						○		○							
VIIb. Ground TA - Thermal		●				○										
VIIc. Ground TA - Propulsion			●							○						
VIII. Pathfinder									○	○	●		●			
IX. Certification/Prototype					○	○	○				○	○	○			
X. Avionics development hdwe.				○	●				○							

TA = Test Article
M/U = Mockup

Primary use: ● Secondary Use: ○

Table 13.4-2 identifies the minimum number of tests required to verify a recovery system for the PLS. Additional government certification requirements are not addressed in this report. Section 13.4.2 provides the reader with a more complete list of testing assumptions.

The establishment of this Phase C/D Test program was based on a review of NASA's experience with the Apollo Program's launch escape method. It includes the Launch Escape System (LES) tests described below, and four flight tests of the PLS/ALS.

13.4.1 Launch Escape System Testing

Tests to verify the LES include both tests for abort capability in flight and tests for abort from the pad (or T-0 aborts). Ten launches using Delta or Atlas class boosters are anticipated with aborts occurring at various altitudes. Table 13.4.1-1 provides a summary of the mission objectives for the flight tests and the in-flight LES tests. The T-0 tests could be conducted off of a test stand or booster simulator.

The required test articles consist of a mass simulator structure with a recovery system and the LES. A more detailed description of these items is provided in the following section.

Refurbishment, build-up and test article integration will be accomplished in the PLS facility. The booster to test article interface will include the PLS abort interface to verify function of abort initiation. Test articles will be recovered in the Atlantic Ocean for refurbishment and reuse. Proper scheduling of these tests may allow the LES recovery test article to also function as tests of the recovery system.

There are some issues which will need to be addressed as the test program is defined in more detail. There may be some range safety concerns with having ten Delta or Atlas launches where the booster does not reach orbit. Additionally all 10 of the launches are currently scheduled in one year. This may present some launch scheduling problems depending on the traffic. Finally, the booster will have to be selected. The use of Titan II's are also a possibility for these LES tests.

Table 13.4-2 Recovery System Test Program

- All unmanned tests
- Mass simulated vehicle with selected additional hardware
- Each class of test (reference number) may entail several "flights"

Reference No	1	2	3	4	5	6	7	8
V_{max} (kts)	0	0	~40	~40	~400	~400	~400	~400
			← Tower or He	licopter Drops →	← C-5 a	erial deployment	→	
Additional Hardware	LIA hardware Stability hdw (if separate)	Floatation/ stabilization hardware	LIA hardware	Water impact attenuation hardware (if any)	Primary decelerator w deployment chutes LIA hardware	Primary and backup decelerator LIA hardware	Decelerators sensors, actuation, sequencer, LIA hardware	Decelerators, integrated GN&C, LIA hardware
Test Objectives	• Determine land stability in winds/ varied slope • Ground recovery procedures	• Determine water stability in winds/ sea states • Water recovery procedures	• Impact loads verification • Stability tests • Separation from decelerator (chutes)	• Impact loads verification • Stability tests • Separation from decelerator (chutes) • Floatation device deploy	• Deployment sequencing tests • Deployment loads	• Backup device deployment (simulated failure)	• Control response tests • Sensing of altitude, velocity, winds	• Full-up on-board landing sequence • Expansion of safe landing envelope

LIA = Land Impact Attenuation

Table13.4.1-1 LES and Flight Test Design

	LES Tests		Flight Tests			
Crew	0	0	0	0	2	2
Test Duration	5 min.	15 min.	1 orbit	10 orbits	3 days	7 days
PLS Vehicle	Mass Sim.	Mass Sim.	Instrumented R/C Mass Sim.	Cert/Proto unit	Cert/Proto unit	Cert/Proto unit w/target
Mission Objectives	"Off-the-Pad" Abort	"Worst q" Abort	• Nominal loads Verification • Recovery Systems Test	• Full GN&C Test • Avionics	• Handling • ECLSS • Sim. dock & servicing	• Manual dock Rendevous • Extend ECLSS • Servicing Test • Evacuation Drills

13.4.2 Test Articles

A summary definition of the test articles is shown below and provided the rationale for the cost estimations:

I <u>Engineering Mockup(s):</u>

Class I mockup will be performed electronically in CAD/CAM computers. Incrementally refined class II/III mockup will be evolved to perform the following functions:

a) Form/fit/function tests

b) Access verification

c) Human factors/ergonometricsevaluations and refinements

d) Training and crew familiarization (special access doors)

e) Procedures development and training

f) Public relations

II <u>Flight Simulator(s):</u>

A separate facility will be a flight simulator, duplicating seats, controls and displays, and interior elements in a dynamic, iterative simulator used for training and to verify procedures and human factors for flight elements involving crew members. Early versions would be static seat/controls and displays arrangement. The STS orbiter simulator (or new equivalent) would be available later.

III Recovery Systems Simulator:

A complete structural article with TT&C and unique instrumentation, with mass properties identical to a flight article and will have the external contours, hardpoints, and recovery/ landing equipment of an operational PLS and will be used for:

a) Airborne drop tests/decelerator development and verification

b) Impact attenuation hardware development and verification

c) Seaworthiness evaluations

d) Transportation and handling interfaces with ground elements

e) Similar to "captive" flight test article requirements

IV "Iron bird"/Systems Integration Facility (SIL):

A facility to test interfaces and functional relationships between non-structural subsystem elements. Also used to verify power and cooling requirements. Systems integration Lab hardware consisting of one set of all-up avionics, power, racks, wiring, thermal control equipment and ECLSS. Later adaptation to SIL during operational period of PLS.

V Launch Escape System Simulator:

An article (a complete structural article with TT&C and unique instrumentation) with mass properties identical to a flight article that will have the external contours of an operational PLS and will be used for launch escape systems tests/verification. Includes rocket motors and any attachment hardware and recovery devices. Two units built in case of system failure.

VI Neutral Buoyancy Mockup/EVA Simulator

An unpowered, underwater mockup used to train/verify EVA procedures and proximity operations (identical to engineering class II mockup).

VII <u>Full ground test articles:</u>

Structural/propulsion test article (one test to failure, one tested to limits) and any coupon/subassembly test article to:

a) Proof loads (flight and pressure)

b) Thermal tests

c) Test to failure (fail-safe)

d) Interface verification with other elements (LV, LES, propulsion, ground equipment, SSF, etc.)

VIII <u>Pathfinder:</u>

An article used to verify facilities/procedures flow. This article is a full mass simulation with all external interfaces - structural and other. This could be the Certification/Prototype unit or a structural test article or a recovery system simulator if schedule permits multiple uses of these articles.

IX <u>Certification Prototype unit(s):</u>

Provide full functional verification capability including launch and reentry tests. Convertible to operational unit. (Flight test unit = 1 each).

X <u>Avionics development hardware:</u>

For all new hardware, assume the following test/development quantities:

	Component Development	Prototyping & Environmental Test	Subsystems Qualification (Units)
Digital	1 breadboard	2+above	1 unit
Analog/Ctrl	1 engr. model	1+above	1 unit
Power	2 engr. model	1+above	1 unit

For existing design, recertified to new integration specifications, assume the following test/development quantities:

	Component Development	Prototyping & Environmental Test	Subsystems Qualification (Units)
Digital	N/A	1+above	1 unit
Analog/Ctrl	N/A	1+above	1 unit
Power	N/A	1+above	1 unit

13.5 Manufacturing

Table 13.5-1 provides a final test hardware matrix which identifies hardware elements necessary to satisfy each test requirement. A Theoretical First Unit (TFU) flow schedule was developed (Figure 13.5-1) which provides estimated flow times required for procurement, fabrication, final assembly, and final acceptance test of each subassembly. Table 13.5-2 provides the manufacturing lot buy plan information. Fiscal year production quantities are identified as well as the lot buy plan for the first mission.

13.6 System Technologies

The LOX-RP system which will be utilized in the PLS OMS and the LES requires a significant amount of technology development. Figure 13.6-1 provides a description of the technology levels in terms of the NASA maturity scale. Each hardware element of the PLS system is identified in Table 13.6-1 along with the assumed technology application and required maturity level.

Table13.5-1 Test Hardware Matrix

Test Requirement	Quantity of Hardware Planned					
	Structures	LES	OMS Eng.	Avionics	LSS	Chutes
Static & Thermal	1 (incl.TPS)	-	1 Eng.	-	-	2 sets
Dynamic & Failsafe	1	-	-	-	-	6 sets
Mockups & Trng.	0.3 (use static)	1	3 Eng.	1	0. 5	-
Recovery Simul.'s	0.5	-	-	1	-	25 sets
LES Simulator	0.5 (mass sim.)	5	-	1	-	10 sets
Qual./Pathfinder	Proto #1 -- Proto #1					
Avionic/LSS labs "Iron Bird" & SIL S/W Dev. Facility	- 0.1 (equip.) 0.1 (equip.)	- Ctrl. & Valves	- Fld. Sply. Controller	1 1 1	1 0.3 0.2	- 0.5 0.5
Propulsion Tests	0.5	4 Eng.	9 Eng.	-	-	-
Protoflight Vehicles	2 (incl. TPS)	2	6 Eng.	2	2	4 sets
Totals (equiv. units) - (subsystems)	6.0 Struc. 5.0 TPS	12.0 Eng. 13.0 Equip.	19.0 Eng.	8.0	5.0	47.0 Chutes 9.0 Equip.

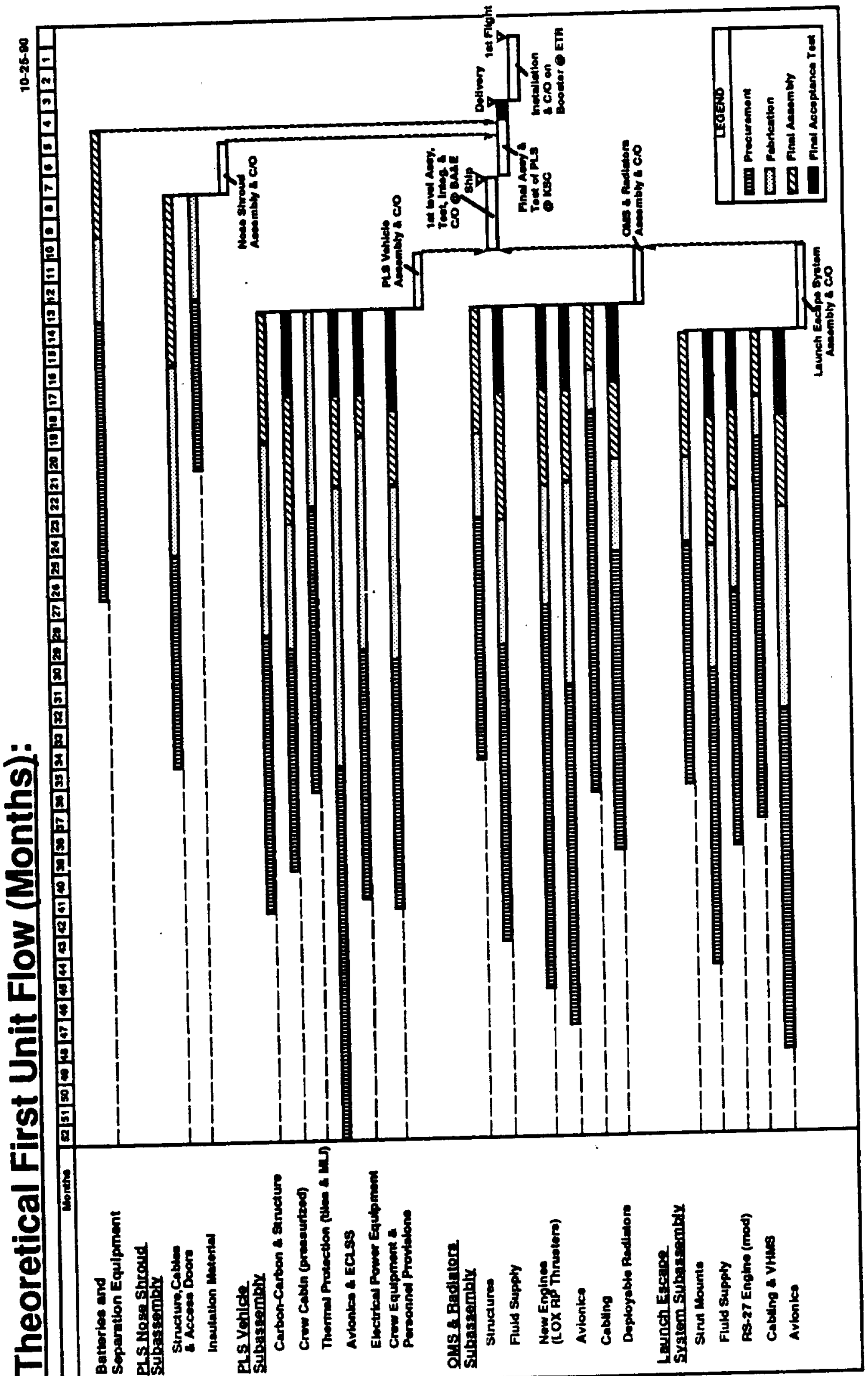

Figure 13.5-1 PLS Manufacturing Planning

Table 13.5-2 PLS Manufacturing Lot Buy Plan

Production Quantities By Fiscal Year Buy:

- Primary missions for PLS requires only five vehicles.
- The actual mission will need only three operational units with allowance for unplanned maintenance events.
- Two operational spare vehicles: one for operational availability (e.g. - for vehicle loss or emergency rescue mission); and one for a scheduled maintenance spare.

Fiscal Year Lot Buy Plan (Primary DRM 1 Mission Only):

Fiscal Year	Lot Buy No.	Vehicle Number	Delivery Year
FY 1996	Long Lead #1	Prod. #1 Parts	FY 1997-8
FY 1998	Lot Buy #1	Prod. #1	FY 2000
		Prod. #2	FY 2000
		Proto Mod. (#3)	FY 2001
FY 2000	Long Lead #2	#4 & #5 Parts	FY 2001
FY 2001	Lot Buy #2	Prod. #4	FY 2002
		Prod. #5	FY 2003

Level	Level Description
1	Basic Principles Observed and Reported
2	Conceptual Design Formulated
3	Conceptual Design Tested Analytically or Experimentally
4	Critical Function/Characteristic Demonstration
5	Component Brassboard Tested in Relevant Environment
6	Prototype/Engineering Model Tested in Relevant Environment
7	Engineering Model Tested in Space
8	"Flight-Qualified" System
9	"Flight-Proven" System

Technology Development

Advanced Development

Flight Systems

Figure 13.6-1 Technology Level Scale

Table 13.6-1 PLS System Technologies

WBS Items	Technology Application Assumed	(NASA Maturity Scale) Technology Level (Average)
Hardware:		
Structures & Mech.	Aluminum; Honeycomb; Graphite Composites	Level 9
Thermal Control	MLI Blankets; Mech. Attachment; Adv. Radiators	Level 5
Life Support Systems	Existing STS Technology Application Systems	Level 9
Propulsion	1990 Technology Engines - OMS (new qual.)	Level 7
Reaction Control	Integrated Systems + N2 Cold Gas	Level 9
Power Subsystems	New Batteries (1992); Adv. STS Fuel Cells	Level 6
Guidance, Nav., Ctrl.	2nd Gen. Ring Laser Gyro's; Adv. SAR Radar	Level 7
Com. & Data Hdlg.	GPS/ATRDSS; Fiber Optics; Adv. Processor	Level 5
Wiring & Instru.	Power - High Efficiency Wire; Digital - Fiber Optics	Level 9
Software (Veh.)	Expert Systems; Ada ; LISP; C Applications	Level 5
Assy. & Checkout	Automated Checkout Test Stations; VHMS Database	Level 6
Support Equipment	Redundant, Fully-Automated Test Equip.; BIT	Level 6
System Test Operations	High Rel.; 2-Fault Tolerant (NASA STD-3000)	Level 6
Satellite Servicing	New EVA Suit; Adv. Solar Cells; Telerobotics Arms	Levels 4 & 5

13.7 Test to Operations Transition

The PLS program schedule (presented as Figure 13.2-2) shows the schedule for transition from test to operations. Two protoflight vehicles are built in Phase C/D with four vehicles being built in the production phase. In the operational phase, five vehicles will be available as the second protoflight vehicle will be modified to become the PLS operational spare. The groundrules for the transition from the Test phase to the Operational phase are as follows:

- The flight tests will be accomplished after pathfinder verification in operational site facilities. Site activation and operational facility's availability is critical to both DDT&E and operational system mission success.
- The PLS #1 vehicle (protoflight #1) will serve as the qualification vehicle and then be used for two flight tests. This vehicle will become a DDT&E testbed and residual spares asset for protoflight unit #2.
- PLS protoflight vehicle #2 will be used for two flight tests and will become the first operational mission unit. This vehicle will later be modified to become the PLS vehicle operational spare.
- Two production units will be ordered in the first production lot buy and will work, with protoflight vehicle #2, in the initial operating years.
- Every vehicle will be ordered with 10 percent spares.
- All ground support equipment is bought in Phase C/D.

13.8 Program Coordination/Interfaces

Any time a new element is added to the space infrastructure, coordination among existing and planned programs must be considered. For example, the mission to provide SSF rotation requires that several PLS/SSF hardware and operational interfaces be considered. The Space Station is currently requiring that the SSF grapples and docks any incoming vehicle, as opposed to the vehicle itself effecting the docking. This will require physical interface coordination with the docking ring, grappling fixture, environmental control (atmospheric, thermal isolation), and data

connections. As well as the hardware interfaces, operational interfaces will need to be defined such as flight rules (command and control), communications (voice, positional data), and interference (thruster impingement, contamination, thermal contamination, shadowing, visibility, c.g./inertia changes, and RMS envelope restrictions).

The PLS may also require interfaces with the STS. DRM 2 is the mission where the PLS serves as an ACRV. In this function, the PLS/ACRV might be launched or returned in the STS cargo bay. Physical interfaces such as the payload bay hard points/trunnions, data connections, etc. as well as operational interfaces such as flight rules and c.g. impacts will need to be addressed.

In addition to these system interfaces, a short list is provided below of some of the other infrastructure elements and interfaces which will require consideration:

Facilities and Navigation/Communications

KSC - Facilities, personnel, planning, GSE

JSC - Mission control, mission planning, personnel provisions preparation, training facilities and personnel

TDRS - Frequency, antennas, etc., planning for shared usage

GPS (or Glonass) - Frequency, antennas, etc., blackout analysis

Transport and Services

Air Transportation (C-5/C-17) - Envelope clearances, weight/c.g., MAC conflicts/availability, pallet hold-downs

Search & Rescue Forces - Locator beacons, communications, lift points, external access, safing provisions

Civilian Infrastructure - Air traffic control, communications, media

14 LIFE CYCLE COST ANALYSIS

During this study, cost estimates have been developed for several preliminary vehicle concepts. These estimates contain the development and manufacturing costs for PLS hardware and flight software, operational costs per flight, and projected life cycle costs. Cost estimates were also developed to support the trade studies performed in tasks 2a and 2c.

14.1 Cost Analysis Methodology

STS Orbiter actuals for flight 31 and flight 51L operations were used to develop preliminary labor hour estimates for PLS vehicle refurbishment operations. Many of the STS Orbiter tasks were reduced based on the simpler PLS design concept which has design requirements for maximum modularity and for 50 reuses. Figure 14.1-1 is an example of STS Orbiter summary data that was used for PLS estimating.

Vehicle launch preparation for the biconic vehicle was estimated by first defining preliminary work packages and operational flow diagrams. Task direct estimates, at a top-level (equivalent heads), were then developed from the work package and operations flow descriptions.

Processing facilities and support equipment at the primary launch site were estimated from preliminary conceptual design information. The preliminary design parameters included gross and dry vehicle weight, vehicle dimensions, and assumptions as to the level of processing automation. Due to the small vehicle size, the PLS vehicle can be transported in much smaller transports and assembled in smaller facilities than the Shuttle Orbiter.

Development and manufacturing of the vehicle hardware was estimated by parametric modeling techniques. The Boeing proprietary "Parametric Cost Model" (PCM) was used to determine the development phase and production theoretical first unit (TFU) estimates. The estimates were developed in constant-year 1989 dollars. PLS weight estimates, physical description design data, and "similar-to" hardware unit estimates (mostly major propulsion, avionics, and life support system hardware), were used as inputs to the Boeing PCM. Through-puts of hardware items which are normally purchased were validated through discussions with the appropriate hardware suppliers. Figure 14.1-2 illustrates the Boeing PCM estimating process.

	2	3	4	5	6	7	8	9	10	11

TABLE 1.1
STS-31 PROCESSING MANHOURS
TECH & ENGR ACTUALS - OTHERS RATIOED

[redacted]

TASK	MT	TECH	ENGR	SAFETY	QUALITY	PP&C	SUPT	LOG	OH	MAN HRS
LANDING - DFRC X .5	MORTON THIOKOL (SRB)	2714 5428	559 1117	217 434	1032 2063	597 1191	5021 10042	1439 2877	1140 2230	12543 25434
OPF - ORBITER PROCESSING		13,149 33037	11,824 31096	1013 3123	5,185 11834	3003 8488	25,255 72218	7,236 20630	5,738 16396	72,983 208981
UNSCHEDULED MAINT X .5		1244 2488	784 1567	100 199	473 945	274 547	2302 4603	660 1319	526 1045	6357 12713
SCHEDULED MAINT										
[redacted]										
01 QUAL ENGR X .8		816 1020	726 908	66 82	310 388	179 224	1510 1887	433 541	342 428	4382 5477
03 INTEGRATION		126	166	15	71	41	344	99	78	999
05 P V & D X .8		525 656	467 584	42 52	199 249	115 144	971 1214	278 348	221 276	2018 3523
07 MECHANISMS X .5		806 1611	717 1421	65 129	306 612	177 354	1490 2980	427 854	339 677	4326 8651
08 STRUCT/HANDLG X .25		733 3932	652 2609	59 235	279 1117	161 645	1356 5423	389 1554	308 1231	3936 15745
09 TPS X .2		2127 10635	1893 9465	170 851	808 4042	468 2340	3935 19677	1127 5637	893 4467	11,423 57115
[redacted]										
43 REACTION CNTL		1266	1146	103	469	283	2363	663	541	6917
45 FUEL CELL/PRSD		248	221	29	94	55	459	131	104	1332
[redacted]										
50 LAUNCH ACCCESS		90	89	7	34	20	167	43	38	483
[redacted]										
55 FRYO/RNG SFTY		292	260	23	111	64	510	155	123	1568
[redacted]										
60 ENVR CNTL/LIFE		1724	1534	138	655	379	3169	914	724	9258
66 FLT CREW SYS		208	185	17	79	46	385	110	87	1117
70 GUID & NAV		780	694	62	296	172	1443	413	328	4189
73 DIGITAL SYS		226	201	18	86	50	418	120	95	1214
74 COMM & TRACK		135	120	11	51	30	250	72	57	725
75 INSTRUMENTATIO		76	68	6	29	17	141	40	32	408
76 ELEC PWR DIST		224	199	18	85	49	414	119	94	1293
93 ON-BOARD SW		80	71	6	30	18	148	42	34	430
ORBITER SHOPS X .8		1579 1974	1406 1757	126 158	600 750	347 434	2922 3652	836 1045	663 823	8480 10603
MODIFICATIONS		264	235	21	100	58	488	140	111	1418
VAB INTEGRATION X .8	2085 2608	2324 2905	1036 1282	186 232	883 1104	511 639	4299 5374	1232 1540	976 1220	13522 16902
PAD OPERATIONS X .8	11492 14365	19858 24823	11,793 14741	1589 1986	7546 9433	4369 5461	36,738 45923	10,525 13156	8341 10425	112,250 140313
TOTAL WITHOUT OVERTIME	16971	72193	54256	5775	27433	15882	133557	39262	30321	394631
[redacted] (20% O/T TYPICAL)	13,577	38,545	25,202	3085	14,646	8480	71,313	20,432	16,195	211,474

Figure 14.1-1 STS Orbiter Processing – Post Flight Maintenance

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Boeing PCM Estimating Methodology

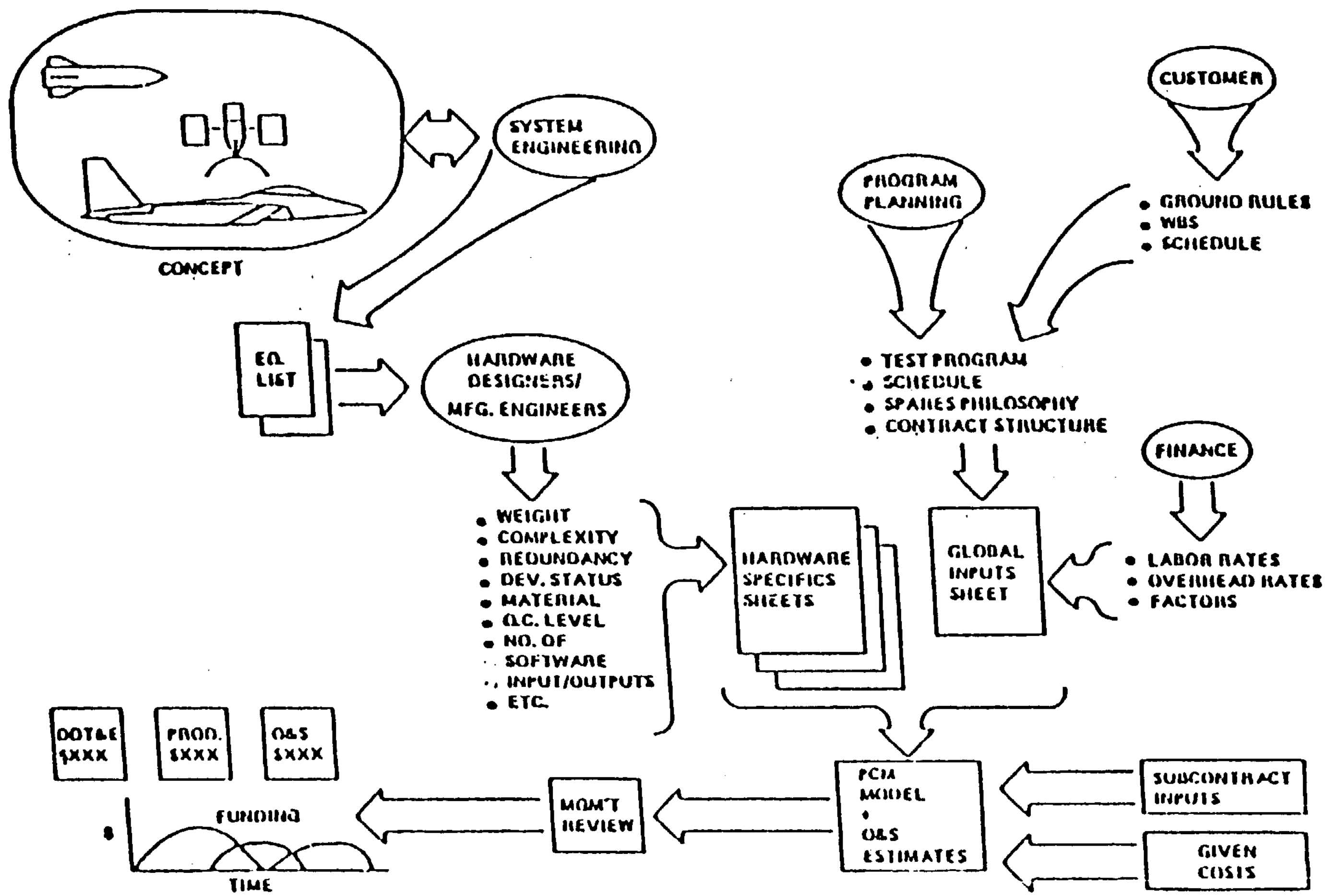

Figure 14.1-2 Boeing Parametric Cost Model Methodology

Software lines of code estimates were developed using data from the Shuttle, from B1-B avionics requirements, and from the Inertial Upper Stage (IUS) and 747-400 commercial airplane (advanced cockpit and imbedded software development) programs. The lines of code estimates were loaded into the Price-S software cost estimating model and output in constant-year 1989 dollars.

Cost risk analysis was accomplished using the Boeing "Ranger" cost uncertainty model. Inputs for the Ranger model were developed using structured questionnaire forms (Figure 14.1-3) which were collected from subsystem designers using a modified "Delphi" method. The Ranger model uses skewed distribution (unimodal) curves generated from the subsystem questionnaires.

14.2 Estimating Groundrules and Assumptions

The work breakdown structure (WBS) used for cost analysis of the Boeing PLS configurations was supplied by NASA. All technology applications were targeted for a 1992 maturity point. The mission models provided by NASA were analyzed and used to establish passenger levels, yearly flight rates, and the requirements for the first operational flight year. Table 14.2-1 contains the mission model flight schedule used for midterm program planning and life cycle cost (LCC) estimates.

The final review mission model groundrules were revised as a sensitivity study to exclude satellite servicing. Table 14.2-2 shows the subsequent mission model over the same operational period but reduced by 104 flights. The assessment of the impact on the LCC is that the reduction in the mission model significantly increases the average cost per flight.

Figure 14.2-1 is the PLS master program schedule for the LOX/RP system which was used for the final LCC estimate. The program schedule, a preliminary biconic vehicle conceptual design (Figure 5.0-1), and subsequent LOX/RP vehicle conceptual design drawings formed the basis for the preliminary planning LCC estimates and for the cost support provided to the trade studies.

The point of departure vehicle design includes an Orbital Maneuvering System (OMS) which uses NTO/MMH propellants and a solid propellant, tractor-type LES rocket. The final selected configuration uses LOX/RP for the OMS and has a different launch escape system configuration.

RANGER COST UNCERTAINTY MODEL

INPUT FORM

CASE ____________________

DEPEND ________

Costs to be Evaluated			Uncertainty Factors			
Cost Element Name	$Estimate$ With Contingency	$Estimate$ W/O Contingency	Schedule	Program Definition	Technical Challenge	Estimating Approach

Figure 14.1-3 Ranger Cost Model Input Form

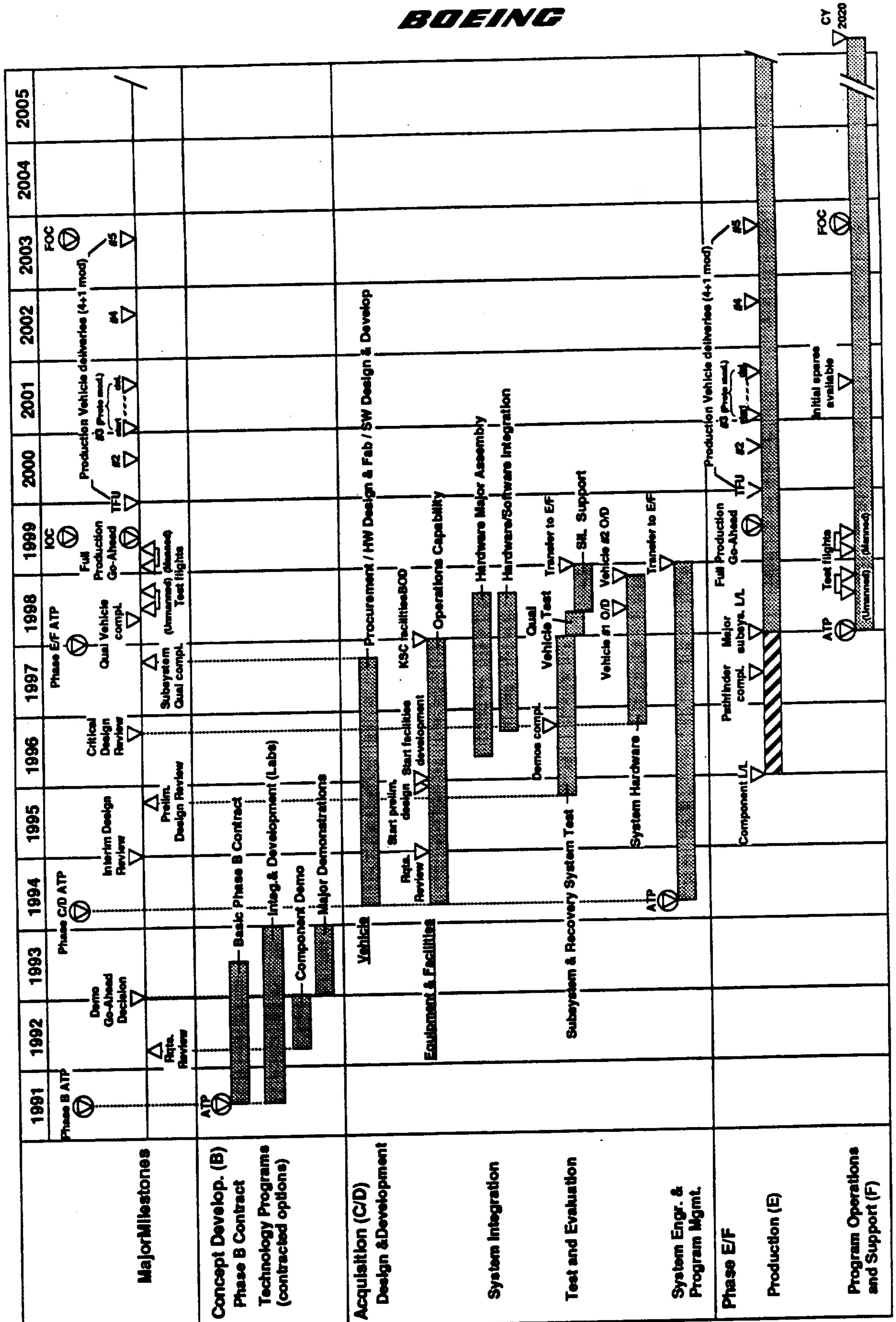

Figure14.2-1 PLS Master Program Schedule

Table 14.2-1 *Mission Model Groundrules*

Personnel Size:	10	4	10	(TEST FLTS)
Flight Mission:	**Station**	**Servicing**	**Lunar/Mars**	**Total**
1996 GROUND TESTING				0
1997 QUAL. TESTING				0
1998 FACILITIES SETUP				0
1999 UMANNED FLT TEST				0 (2) Unmanned
2000	1	1	0	2 + (2) Manned
2001	2	2	0	4
2002	3	2	0	5
2003	4	3	2	9
2004	5	3	2	10
2005	5	3	2	10
2006	6	6	2	14
2007	6	6	2	14
2008	6	6	2	14
2009	6	6	2	14
2010	6	6	2	14
2011-2019	(SAME RATES PER YEAR AS 2010)			126 (14/Yr.)
2020	6	6	2	14
Total	110	104	36	250 + (4) First Times
Average	4.4	4.2	1.4	10

Table 14.2-2 Primary Missions for Evaluation

Personnel Size:	10	10		(TEST FLTS)
Flight Mission:	Station	Lunar/Mars	Total	
1996 GROUND TESTING			0	
1997 QUAL. TESTING			0	
1998 FACILITIES SETUP			0	
1999 UMANNED FLT TEST			0	(2) Unmanned
2000	1	0	1 +	(2) Manned
2001	2	0	2	
2002	3	0	3	
2003	4	2	6	
2004	5	2	7	
2005	5	2	7	
2006	6	2	8	
2007	6	2	8	
2008	6	2	8	
2009	6	2	8	
2010	6	2	8	
2011-2019	(SAME RATES PER YEAR AS 2010)		72	(8/Yr.)
2020	6	2	8	
Total	110	36	146 +	(4) First Times
Average	4.4	2.0		

* satellite service units not included in the final planning until better ops. definition is available

* NOTE: Satellite servicing mission LCC analysis has been deferred until a later date.

Additional program planning software and facilities requirements were derived from several technical interchange meetings with the JSC program office and other NASA center personnel. Software development requirements were established for avionics development, vehicle flight software, and the software development facility. Preliminary training, KSC operations, and mission control facilities development assumptions were also established.

Mission needs were groundruled for the PLS vehicle. The primary mission need is for PLS to provide crew rotation service from Earth to SSF. Secondary missions include satellite servicing and other low Earth orbit missions. Initial LCC estimating was primarily focused on the crew rotation requirements. Secondary focus was directed at the definition of kits to support satellite servicing (the scenario for satellite servicing is not as well defined). Test hardware requirements were established for LCC estimates using hardware allocation matrices and a preliminary system test and evaluation schedule.

The final review test hardware allocation matrix is shown in Table 14.2-3. Cost sensitivity runs were developed during the study which included more test units and as little as four equivalent units of test hardware during the development phases of the program. The final allocation matrix is an optimized quantity set based on the preliminary sensitivity studies and cost risk assessments.

Table 14.2-4 summarizes the key groundrules and assumptions used to generate the final LCC estimates. Hardware quantities and mission model groundrules were varied over the study to investigate impacts on system LCC's.

14.3 Life Cycle Cost Summaries

The point-of-departure (POD) biconic vehicle system, with NTO/MMH propulsion, was estimated several times during the study. Each successive estimate was developed with additional software and facilities cost estimates. The OMS propulsion subsystem was re-estimated with different (lower cost) hardware components at the third quarterly review. This cost estimating exercise formed the lower boundry of the PLS program flight hardware estimates.

Software estimates were incrementally added to the LCC estimates throughout the study. See section 14.5 for the software estimate summaries.

Table 14.2-3. Final Test Hardware Matrix

Test Requirement	Quantity of Hardware Planned					
	Structures	LES	OMS Eng.	Avionics	LSS	Chutes
Static & Thermal	1 (incl.TPS)	-	1 Eng.	-	-	2 sets
Dynamic & Failsafe	1	-	-	-	-	6 sets
Mockups & Trng.	0.3 (use static)	1	3 Eng.	1	0. 5	-
Recovery Simul.'s	0.5	-	-	1	-	25 sets
LES Simulator	0.5 (mass sim.)	5	-	1	-	10 sets
Qual./Pathfinder	Proto #1					Proto #1
Avionic/LSS labs	-	-	-	1	1	-
"Iron Bird" & SIL	0.1 (equip.)	Ctrl. &	Fld. Sply.	1	0.3	0.5
S/W Dev. Facility	0.1 (equip.)	Valves	Controller	1	0.2	0.5
Propulsion Tests	0.5	4 Eng.	9 Eng.	-	-	-
Protoflight Vehicles	2 (incl. TPS)	2	6 Eng.	2	2	4 sets
Totals (equiv. units) - (subsystems)	6.0 Struc. 5.0 TPS	12.0 Eng. 13.0 Equip.	19.0 Eng.	8.0	5.0	47.0 Chutes 9.0 Equip.

Table 14.2-4. Final Estimating Groundrules

- New hardware description for LOX-RP system and new Launch Escape System (LES) concept (liquid pusher).
- All estimates in 1989 dollars including 25% requirements change factor, 10% contractor fee, and 5% NASA support.
- DRM 1 mission model used for analysis (146 sorties).
- 50 reuses of operational vehicles, with KSC refurbishment.
- Four flight tests with 2 vehicles; 2 unmanned, 2 manned.
- #2 protoflight unit is modified for operational service in production phase; allowance for 1 ops. and 1 maint. spare; 4 production units + 1 mod. in 2 FY lot buys; 10% spares.
- ETR launch site (KSC); new vehicle processing, mission control (JSC), and training (JSC) facilities; ground control software is not addressed.
- 15% schedule compression penalty and 15% weight growth.

Table 14.3-1 contains the first LCC estimate produced during the study. The original baseline estimate was developed for an eight (8) person vehicle (6 passengers and 2 crew). Sensitivity trades of passenger count capability versus system LCC (Section 5.1.1) were accomplished to help select a cost effective configuration. Therefore, the passenger size vs. cost trade study results were used to resize and re-estimate the vehicle for 10 personnel (8 passengers and 2 crew).

The point-of-departure (POD) system LCC summaries for the 10-personnel biconic NTO/MMH conceptual designs are shown in Tables 14.3-2 and 14.3-3. Table 14.3-2 was presented at the midterm review. Table 14.3-3 is a revised estimate from the third quarter review. The third quarter review estimates included the lower cost NTO/MMH OMS hardware, a new software estimate for the avionics lab, and a new training facility estimate.

The new LOX/RP system LCC estimate, which includes the development of a new LOX/RP OMS thruster and which was presented at the final review, is shown in Table 14.3-4.

14.4 Preliminary Program Cost Risk Assessment

A cost uncertainty (risk) model was run to evaluate the impact during the development phase of expected delays and test failures or unexpected test successes. The midterm cost risk analysis results are displayed in Table 14.4-1. The inputs to the "Ranger" uncertainty model included the midterm Phase C/D estimate from the Boeing Parametric Cost Model (PCM).

A two-year compression of the development schedule could occur for the PLS program. PCM was used to estimate the impact on system design for this compression. The result of this compressed schedule cost analysis is shown in Table 14.4-2. The two-year compression evaluation does not include the impact of hardware shortages due to overlaps of test hardware usage requirements (PCM does not have the capability to assess test schedule risk).

The final estimate cost risk analysis is presented in Table 14.4-3. The final cost risk assessment includes revised hardware development test risk evaluations for the new liquid propulsion systems (OMS and LES). Software estimates are not included in the Ranger model output.

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Table 14.3-1 Preliminary LCC Estimate for 8 Person Vehicle

Reference Vehicle Configuration: Crew Rotation, 8 Personnel

	(Constant Year, 1989 Dollars)	
Concept Development & DT&E	$ 3,198	FY 1992-1999
Facilities & Equipment at KSC	322	FY 1992-1999
Production (14 PLS Vehicles)	3,492	FY 1997 (L/L) Thru 2018
Operations & Support (22 Yrs.)		
PLS Operations & Maint.	741	FY 1999 - 2020
Booster Launch Ops.	15,100	FY 1999 - 2020
*Total Life Cycle Estimate -	$ 22,853 Million	

Operational Scenario: Mission Model No. 2 - 12 People at SSF , 302 Flights

Note * Excludes Software (TBD) ; Satellite Servicing Equipment Kits (same for all scenarios); and Booster/Payload DDT&E interface labor estimates (no definition - TBD).

Table 14.3-2 Mid-Term Review LCC Estimate

Reference Vehicle Configuration: Crew Rotation (DRM-1)

		(Constant Year, 1989 Dollars)	
Concept Development & DT&E	$	4,640 *	FY 1992-1999
Facilities & Equipment at KSC		100 *	FY 1992-1999
Production (12 PLS Vehicles)		15,691 *	FY 1997 (L/L) Thru 2018
Operations & Support (22 Yrs.)			
PLS Operations & Maint.		1,745	FY 1999 - 2020
Booster Launch Ops.		12,700	FY 1999 - 2020
*Total Life Cycle Estimate -	$	34,876 Million	

Operational Scenario: Traffic Model B - 12 People at SSF , 250 Flights

Note * INCLUDES Software ; Satellite Servicing Equipment Kits; and a new mission control center ($31.9 M).

Excludes Mission Control Center software (TBD).

Table 14.3-3 Third Quarterly Review LCC Estimate

Reference Vehicle Configuration: Expendable OMS Vehicle Update (POD)

(Constant Year, 1989 Dollars)

Concept Development & DT&E	$	5,309 *	FY 1992-1999
Facilities & Equipment at KSC & JSC		327 *	FY 1992-1999
Production (9 Units & expend+1 mod.)		13,481 *	FY 1996 (L/L) Thru 2017
Operations & Support (22 Yrs.)			
PLS Operations & Maint.		1,745	FY 1998 - 2020
Booster Launch Ops. (revised)		20,320	FY 1998 - 2020
*Total Life Cycle Estimate -	$	41,092 Million	

Operational Scenario: Traffic Model B - 12 People at SSF , 250 + 4 DT&E flt.'s

Note * INCLUDES Software ; Satellite Servicing Equipment Kits;a new mission control center ($31.9 M); and also includes a new training facility & simulators ($227M). Excludes Mission Control Center software (TBD).

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Table 14.3-4 Final Report LCC Estimate

LOX-RP DRM 1 Configuration: Expendable OMS Vehicle Update (POD)

		(Constant Year, 1989 Dollars)	
Concept Development & DT&E	**$**	**6,007***	**FY 1992-1999**
Facilities & Equipment at KSC & JSC		**375***	**FY 1992-1999**
Production (4 Units & expend+1 mod.)		**7,428***	**FY 1996 (L/L) Thru 2003**
Operations & Support (22 Yrs.)			
PLS Operations & Maint. (DRM 1)		**5,501**	**FY 1998 - 2020**
Booster Launch Ops. (Delta/ALS)		**12,300***	**FY 1998 - 2020**
***Total Life Cycle Estimate -**	**$**	**31,611 Million**	

Operational Scenario: Traffic Model B - 12 People at SSF , 146 + 4 DT&E flt.'s

Note * EXCLUDES Ground Control Software; Satellite Servicing Equipment Kits; and Consumables.

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Table 14.4-1 Mid-Term Review Cost Risk Analysis Results (Page 1 of 2)

COSTS TO BE EVALUATED		UNCERTAINTY FACTORS				COST RANGE (DEPENDANCY = 1)		
LINE ITEM NAME	$ ESTIMATE	SCHEDULE	DEFINITION	TECHNICAL	ESTIMATING	LOW	COST RANGE 50/50	HIGH
ENGINEERING						ENGINEERING		
STRUCTURES & MECHANISMS	109.01	4	5	4	7	90.48	143.34	196.21
THERMAL PROTECTION SYSTEM	20.84	4	5	4	7	17.30	27.41	37.52
LAUNCH ESCAPE SYS & FAIRING	141.84	4	5	4	7	117.73	186.53	255.32
PROPULSION/REACTION CTRL	12.47	5	4	3	4	10.66	12.99	15.58
OMS MODULE & ADAPTER	38.31	3	3	2	5	33.33	37.92	44.06
ELECTRICAL POWER	163.36	5	5	6	5	132.73	168.46	204.20
AVIONICS	102.39	5	5	6	5	83.19	105.59	127.98
ENVIRONMENTAL CTRL & LIFE SU	30.88	5	5	5	5	25.09	31.84	38.60
PERSONNEL PROVISIONS	6.27	3	4	4	6	5.33	6.36	7.52
RECOVERY & AUXILIARY	29.03	5	5	5	4	23.95	30.12	36.29
LANDING GEAR SYS	12.60	5	5	5	5	10.24	12.99	15.75
WT GROWTH MARGIN	5.47	5	5	5	5	4.45	5.65	6.84
MANUFACTURING						MANUFACTURING		
STRUCTURES & MECHANISMS	156.20	4	5	4	7	129.65	205.40	281.16
THERMAL PROTECTION SYSTEM	28.09	4	5	4	7	23.32	36.94	50.57
LAUNCH ESCAPE SYS & FAIRING	207.66	4	5	4	7	172.36	273.08	373.79
PROPULSION/REACTION CTRL	66.63	5	4	3	4	56.97	69.43	83.29
OMS MODULE & ADAPTER	276.08	3	3	2	5	240.19	273.26	317.49
ELECTRICAL POWER	163.13	5	5	6	5	132.55	168.23	203.92
AVIONICS	442.44	5	5	6	5	359.48	456.26	553.04
ENVIRONMENTAL CTRL & LIFE SU	80.02	5	5	5	5	65.02	82.52	100.02
PERSONNEL PROVISIONS	70.20	3	4	4	6	59.67	71.23	84.24
RECOVERY & AUXILIARY	24.73	5	5	5	4	20.40	25.66	30.91
LANDING GEAR SYS	15.73	5	5	5	5	12.78	16.22	19.66
WT GROWTH MARGIN	14.02	5	5	5	5	11.39	14.46	17.53
HARDWARE FINAL ASSY & C/O	202.74	5	5	5	5	164.73	209.08	253.43
SPARES	154.49	5	5	5	5	125.53	159.32	193.12
SUPPORT						SUPPORT		
SYSTEM ENGINEERING & INTEGRA	58.27	5	5	5	5	47.35	60.10	72.84
SOFTWARE ENGINEERING	0.0	5	5	5	5	0.0	0.0	0.0
SYSTEMS GROUND TEST CONDUCT	155.40	5	5	5	5	126.26	160.26	194.25
SYSTEMS FLIGHT TEST CONDUCT	67.83	5	5	5	5	55.12	69.95	84.79
PECULIAR SUPPORT EQUIPMENT	140.88	5	5	5	5	114.46	145.28	176.10

Table 14.4-1 Mid-Term Review Cost Risk Analysis Results (Page 2 of 2)

SYSTEMS FLIGHT TEST CONDUCT	11.31	5	5	5	5	9.19	11.66	14.13
PECULIAR SUPPORT EQUIPMENT	125.73	5	5	5	5	102.15	129.65	157.16
TOOLING & SPECIAL TEST EQUIP	388.15	5	5	5	5	315.37	400.28	485.18
TASK DIRECT QUALITY ASSURANC	137.33	5	5	5	5	111.58	141.63	171.67
LOGISTICS	47.06	5	5	5	5	38.24	48.54	58.83
LIAISON ENGINEERING	37.66	5	5	5	5	30.60	38.84	47.07
OTHER SUPPORT COSTS	24.00	5	5	5	5	19.50	24.75	30.00
OUTPLANT	0.84	5	5	5	5	0.68	0.87	1.05
PROGRAM MANAGEMENT	0.0	5	5	5	5	0.0	0.0	0.0
	------					------	------	------
PROGRAM TOTAL (NO DEPENDANCY)	2998.72					2467.06	3403.60	4292.23
PROGRAM TOTAL (WITH DEPENDANCY)	2998.72					2467.06	3743.96	4721.45

Table 14.4-2 Compressed Schedule Impact

2 Year Compression of Hardware Development Schedule

Condensed Schedule Estimate	$	3,353 M
Baseline Schedule Estimate		2,999
Increase for 2 Year Compression	$	354 M
Add Requirements Growth Factor		89
Add Contractor Fees		44
Add NASA Program Support		24
Net Increase for a 1998 Target IOC -	$	511 M *

Note: *This analysis excludes the cost impact on software.

Table 14.4-3 Final Cost Risk Analysis Results (Page 1 of 2)

COSTS TO BE EVALUATED		UNCERTAINTY FACTORS				COST RANGE		
						DEPENDANCY = 2		
LINE ITEM NAME	$ ESTIMATE	SCHEDULE	DEFINITION	TECHNICAL	ESTIMATING	LOW	50/50	HIGH
ENGINEERING								
STRUCTURES	109.01	4	5	4	7	90.48	143.34	196.21
THERMAL PROTECTION SYS	20.84	4	5	4	7	17.30	27.41	37.52
LAUNCH SUPT ADTP	10.69	4	5	4	7	8.87	14.05	19.23
LAUNCH ESCAPE SYS	71.14	4	5	4	7	59.04	93.54	128.04
PROPULSION/REACTION CTRL	8.47	5	4	3	4	7.25	8.83	10.59
OMS MODULE	31.74	3	3	2	5	27.61	31.42	36.50
ELECTRICAL POWER	62.29	5	5	6	5	50.61	64.23	77.86
AVIONICS	122.99	5	5	6	5	99.93	126.84	153.74
ENVIRONMENTAL CTRL	30.88	5	5	5	5	25.09	31.84	38.60
PERSONNEL PROVISIONS	5.82	3	4	4	6	4.95	5.91	6.99
RECOVERY & AUXILIARY	54.82	5	5	5	4	45.23	56.88	68.53
LANDING GEAR SYS	12.60	5	5	5	5	10.24	12.99	15.75
WT GROWTH MARGIN	5.47	5	5	5	5	4.45	5.65	6.84
MANUFACTURING								
STRUCTURES	100.82	4	5	4	7	83.68	132.58	181.48
THERMAL PROTECTION SYS	22.47	4	5	4	7	18.65	29.55	40.45
LAUNCH SUPT ADTP	23.25	4	5	4	7	19.30	30.57	41.85
LAUNCH ESCAPE SYS	181.56	4	5	4	7	150.69	238.75	326.80
PROPULSION/REACTION CTRL	47.42	5	4	3	4	40.55	49.42	59.28
OMS MODULE	194.35	3	3	2	5	169.08	192.36	223.50
ELECTRICAL POWER	106.45	5	5	6	5	86.49	109.77	133.06
AVIONICS	300.80	5	5	6	5	244.40	310.20	376.00
ENVIRONMENTAL CTRL	64.02	5	5	5	5	52.01	66.02	80.02
PERSONNEL PROVISIONS	69.10	3	4	4	6	58.74	70.12	82.93
RECOVERY & AUXILIARY	26.56	5	5	5	4	21.91	27.55	33.20
LANDING GEAR SYS	12.38	5	5	5	5	10.06	12.77	15.48
WT GROWTH MARGIN	9.35	5	5	5	5	7.59	9.64	11.68
HARDWARE FINAL ASSY & C/O	156.18	7	5	8	9	128.85	328.57	468.55
SPARES	115.85	5	5	5	5	94.13	119.47	144.82
SUPPORT								
SYSTEM ENGINEERING & INTEGRA	75.87	5	5	5	5	61.65	78.24	94.84
SOFTWARE ENGINEERING	0.0	6	7	5	5	0.0	0.0	0.0
SYSTEMS GROUND TEST CONDUCT	173.44	5	5	5	5	140.92	178.86	216.79

Table 14.4-3 *Final Cost Risk Analysis Results (Page 2 of 2)*

FILE: PLSD   RGROUT   A   KBAE CMS VM/SP R5 8901 05/25/90 .

1**
******************************** RANGER UNCERTAINTY MODEL ********************************
****

28 OCT 1990   FILENAME: PLSD

PERSONAL LAUNCH SYSTEM DEV FILE INC A 15% DEV SCHEDULE

TOOLING & SPECIAL TEST EQUIP	254.38	5	5	5	5	206.69	262.33	317.98
TASK DIRECT QUALITY ASSURANC	130.03	5	5	5	5	105.65	134.09	162.53
LOGISTICS	42.45	5	5	5	5	34.49	43.78	53.06
LIAISON ENGINEERING	32.16	5	5	5	5	26.13	33.16	40.20
OTHER SUPPORT COSTS	18.42	5	5	5	5	14.96	18.99	23.02
OUTPLANT	0.77	5	5	5	5	0.62	0.79	0.96
PROGRAM MANAGEMENT	0.0	5	5	5	5	0.0	0.0	0.0
	------					------	------	------
PROGRAM TOTAL (NO DEPENDANCY)	3475.23					2860.21	3759.03	4673.77
PROGRAM TOTAL (WITH DEPENDANCY)	3475.23					2860.21	4134.93	5141.14

Note: This evaluation <u>excludes</u> software, facilities, and NASA directed program cost estimate factors (req., fees, and NASA program support.)

14.5 Flight & Avionics Software Estimates

Software estimates were developed using the GE Price-S parametric cost model. Table 14.5-1 contains the estimating groundrules used for developing Price-S cost model estimates. An experienced, senior software engineer developed estimates for the number of deliverable "source lines of code" (SLOC) by using STS Orbiter and other historical space program software data.

Table 14.5-2 is the final report flight software development cost estimate summary. The parametric estimates were generated from conceptual software development and function descriptions for the biconic vehicle designs. The flight software development facility (SDF) and vehicle flight software development estimates are summarized in Table 14.5-3. Table 14.5-4 contains the Price-S estimate results for the avionics integration lab (AIL) development software. PLS ground control software cannot be estimated until more descriptive ground control functions (flow diagrams) and tasks are defined.

14.6 O&S and Facilities Estimates

The operations and support (O&S) phase estimate presented at the midterm review was based on significantly lower levels of ground support labor than that required for existing STS Orbiter support. Table 14.6-1 is a summary of the estimated operations and support manpower levels for the Boeing point-of-departure (POD) PLS configuration utilizing an expendable OMS pod (presented at the PLS midterm review). The final operations and support estimate is summarized, by WBS element, in Table 14.6-2.

14.6.1 Comparison of O&S Labor Estimates

The POD estimate assumed labor levels for 250 flights with a mixture of crew rotation, satellite servicing, and lunar transportation system crew delivery missions. The lower mission control and ground checkout head count requirements assume no scientific payload requirements, a highly autonomous PLS vehicle, and the use of advanced vehicle ground checkout equipment with expert system software.

The final report estimate, for two and three shifts of system operations labor, was revised to include a larger factor (three shifts versus two shifts in the midterm POD

Table 14.5-1 Software Estimating Groundrules

- New architecture with no heap and a specific processor compiler.
- AIL and SDF Simulation computers will be dedicated machines.
- Simulation math models will be programmed in Fortran.
- User interface software will be programmed in Fortran & C.
- Avionics diagnostics will be programmed in Assembler.
- Input/output communications and test equipment interface software will be programmed in C and Assembler.
- Flight software will be programmed in Ada.
- Configuration management & download software will be programmed in C language.
- Satellite servicing and ground control software is not addressed.

Table 14.5-2 Final Software Cost Estimate

Software Development	Lines of Code	Estimate (89$M)
Flight Software Estimate	1,573,000	
Flight Software & Test	1,463,000	$ 116.0 M
Software Dev. Facility	110,000	84.1
Purchased Software (7.5%)	117,975	15.0
Avionics Integration Lab Software & Purch. Equip.	615,000	191.9
Software Integ. & Mgmt. (20%)		81.4
Subtotal @ Contractor Cost -		$ 488.4
Program Factors (25%, 10%, 5%)		216.6
Total Estimated S/W DT&E Cost -		$ 705.0 M *

* Note: Excludes approximately $ 370 M for satellite servicing software not required for DRM 1 mission.

Table 14.5-3 Flight Software Cost Estimate

	GE Price-S Cost Model Output		
	DEVELOPMENT RESOURCES	INTEGRATION RESOURCES	ESTIMATED COST (89$M) (WITHOUT AIL S/W)
Flight Software	5,394.2 MM	2048.6 MM	$ 102.3 M
Sys. Test/OT&E		993.5	13.7
Software Development Facility (SDF)	5,541.8 MM	573.0 MM	84.1
Labor Subtotal	10,936.0 MM	2,621.6 MM	$ 200.1 M
Purchased S/W	$ 15.0 M		15.0
Total (Less AIL S/W)			$ 215.1 M

Table 14.5-4 AIL Software Cost Estimate

Source Lines of Code (SLOC) Total = 615,000

|------ GE Price-S Cost Model Output & Equip. Estimate ---------- |

DEVELOPMENT RESOURCES	INTEGRATION RESOURCES	ESTIMATED COST (89$M) OF SOFTWARE
11,234.3 MM	869.6 MM	$ 185.4 M
Purchased Equip./Services (software)		6.5 M
Total AIL preliminary estimate -		$ 191.9 M

The PLS Avionics Integration Laboratory (AIL) software development estimate is based on expected DRM-1 crew rotation mission requirements. Additional satellite servicing mission requirements are not defined.

Table 14.6-1 Baseline O&S Estimate Summary

Year	DT & E Flights	Mission Flights	Manpower (Heads): Ground Ops	Manpower (Heads): Mission/Launch Ops	Manpower (Heads): Other Ops.	Heads per Year	(89 $ M) Operations Labor Dollars
1999	2		200	135	50	385	$41.9 M
2000	2	2	254	135	50	439	48.5
2001		4	254	135	50	439	44.7
2002		5	308	200	73	581	62.6
2003		9	525	200	73	798	73.9
2004		10	579	200	73	852	76.7
2005		10	579	200	73	852	76.7
2006		14	795	200	73	1068	88.0
2007		14	795	200	73	1068	88.0
2008		14	795	200	73	1068	88.0
2009		14	795	200	73	1068	88.0
2010		14	795	200	73	1068	88.0
2011		14	795	200	73	1068	88.0
2012		14	795	200	73	1068	88.0
2013		14	795	200	73	1068	88.0
2014		14	795	200	73	1068	88.0
2015		14	795	200	73	1068	88.0
2016		14	795	200	73	1068	88.0
2017		14	795	200	73	1068	88.0
2018		14	795	200	73	1068	88.0
2019		14	795	200	73	1068	88.0
2020		14	795	200	73	1069	88.0
TOTALS	4	250	14,624	4,205	1,537	20,366	1,745.0 M
	Flight Tests	Mission	Manyears (Ground)	Manyears (Mission/Launch)	Man years Others Base	Total Man yearsL	Labor Cost Estimate

Table 14.6-2 Operations and Support Summary

1989 Dollars in Millions

- DRM 1 Operations for 22 years & 150 flights (incl. 4 DT&E):

		Estimated Resources	
- Processing (at KSC)	$	761.0 M	
- Integration		15.6	
- Launch Operations		171.7	
- Mission		484.5	
- Landing/Recovery		31.2	
- Non-Nominal Ops. (O/T @ 15%)		219.6	
- Logistics		120.2	
- Base operations (KSC,JSC)		1,009.2	
Subtotal, O&S Labor Estimate -	$	2,813.0 M	
- Facilities Maintenance (4%/yr.)		330.0	(1999-2020)
- Replenishment Spares (9%)		1,908.0	(Every 2 Yrs.)
Subtotal O&S (less consumables) -	$	5,051.0	
- ALS ETO Services ($80 M/flt.)		22,500.0	(150 flt.'s)
Total O&S Estimate -	$	27,551.0	

- Boeing used STS Orbiter, Apollo, IUS, and ALS data as a basis for developing PLS O&S cost estimates. Additional STS MCC reference data was used for the mission control estimate.

estimate) for base operations support (i.e. fire, safety, security, food services, transportation services, materials storage, tool cribs, and special services). The final report peak and manpower estimates for the crew rotation mission are presented in Tables 14.6.1-1 and 14.6.1-2.

14.6.2 System Operation Facility Estimates

The final review summary of the Boeing PLS facilities estimates is shown in Table 14.6.2-1. Figure 14.6.2-1 is a conceptual design (top view) illustration of the PLS mission training facility which was estimated during the study. The new training facility will provide crew training for satellite servicing missions and personnel training (crew and passengers) on the the more automated crew rotation and Lunar Transportation System personnel delivery missions. Other training at this facility will include ground crew hardware familiarization and mission control personnel training.

The conceptual design for the PLS training facility was derived from both actual commercial/military airplane training center building layout information and from next-generation space program (SSF) facility requirements. The training facility estimate summary is contained in Table 14.6.2-2.

Table 14.6.2-3 contains the PLS Mission Control Facility estimate.

14.7 Preliminary Cost Per Flight Estimates

Preliminary cost per flight estimates for each of the preliminary Boeing biconic vehicle systems are shown in Tables 14.7-1 (midterm review - POD design), 14.7-2 (third quarter review design with satellite servicing flights), and in Table 14.7-3 (LOX/RP final review configuration with reduced mission flights). These cost per flight estimates, in 1989 dollars, assume the use of an Advanced Launch System (ALS) booster.

The estimates indicate a cost per flight range from \$138.7 million to \$213.3 million in constant-year 1989 LCC dollars. The cost per flight estimates vary depending on: the magnitude of program development costs; booster cost per flight estimates; the number of mission sorties; and the definition of program assets (test and production hardware quantities amortized across the number of operational flight years). The most expensive cost per flight estimate is based on a mission model reduced by 104 mission sorties (through elimination of the satellite servicing requirements).

Table 14.6.1-1 Peak O&S Headcount by WBS

DRM 1 Ground/Launch O & S (ALS-Launched):

WBS Item	Peak Headcount	Work Location(s)
Processing/Refurb.(2 shifts)	549 **	KSC or CCAFS
Integration (booster/PLS)	10 **	KSC or CCAFS
Launch Operations	50	KSC or CCAFS
Mission (dedicated PMCC)	150	JSC/KSC/SSF (STF)
Landing & Recovery	20 **	Alternate Emerg. Sites
Non-Nominal Ops. (3rd shift)	(O/T) **	KSC or CCAFS
Logistics & Spares Mgmt.	35	Contractor's Plant
Base Ops.(328)/ S/W Supt.(10)	338	JSC & KSC Support
Total Peak Headcount -	1,152 People	(All Sites)

• Sources of data and assumptions:

1. ** Boeing Aerospace Operations (Cocoa Beach) estimated ground ops.
2. 10 personnel vehicle configuration with ALS launch booster, 1 pad.
3. Kennedy Space Center primary launch site; ground site landings.
4. Shuttle data for OPF scaled down for descoped PLS tasks.
5. New Space Station Control Center factors used in PMCC estimate.
6. Work weeks are five, 8-hour days with two shifts for processing.
7. Three shift mission operations when in orbit near SSF and for surge.

Table 14.6.1-2 DRM 1 O&S Estimated Manpower

Year	DT & E Flights	Mission Flights	Contractor Support Manpower (Heads): Ground Ops	Contractor Support Manpower (Heads): Mission/Launch Ops	Contractor Support Manpower (Heads): Other Ops.	Heads per Year	(89 $ M) Operations Labor Dollars
1999	2		200	135	150	485	$57.5 M
2000	2	1	254	135	150	539	64.1
2001		2	254	135	150	539	60.3
2002		3	308	200	173	681	78.2
2003		6	525	200	273	998	105.1
2004		7	579	200	373	1152	123.5
2005		7	579	200	373	1152	123.5
2006		8	579	200	373	1152	123.5
2007		8	579	200	373	1152	123.5
2008		8	579	200	373	1152	123.5
2009		8	579	200	373	1152	123.5
2010		8	579	200	373	1152	123.5
2011		8	579	200	373	1152	123.5
2012		8	579	200	373	1152	123.5
2013		8	579	200	373	1152	123.5
2014		8	579	200	373	1152	123.5
2015		8	579	200	373	1152	123.5
2016		8	579	200	373	1152	123.5
2017		8	579	200	373	1152	123.5
2018		8	579	200	373	1152	123.5
2019		8	579	200	373	1152	123.5
2020		8	579	200	373	1152	123.5
TOTALS	4	146	11,384	4,205	7,237	22,826	2,593.4 M
	Flight Tests	Mission Sorties	Manyears (Ground)	Manyears (Mission/Launch)	Man years Others Base	Total Man years	Labor (less O/T) Cost Estimate

Table 14.6.2-1 Facilities Estimate Summary

PLS Facility	Location	Estimated Value (89$M)
Vehicle Processing	KSC	$ 36.0 M
Refurbishment Wing	KSC	20.0
Fuel Deservicing Area	KSC	2.5
Engine Test Facilities	LeRC MSFC	(GFS)
ALS Launch Processing	ETR *	(GFS)
C-5 Loading Equip.	Portable	1.5
Landing Site	ETR	6.0
Mission Control Center	JSC	32.0
PLS Training Center	JSC	227.0
Recovery/Other Equip.	ETR	50.0
Total Estimate -		$ 375.0 M

* Note: Assumes ALS docks, roads, and cargo processing facility (adapter processing) are in place.

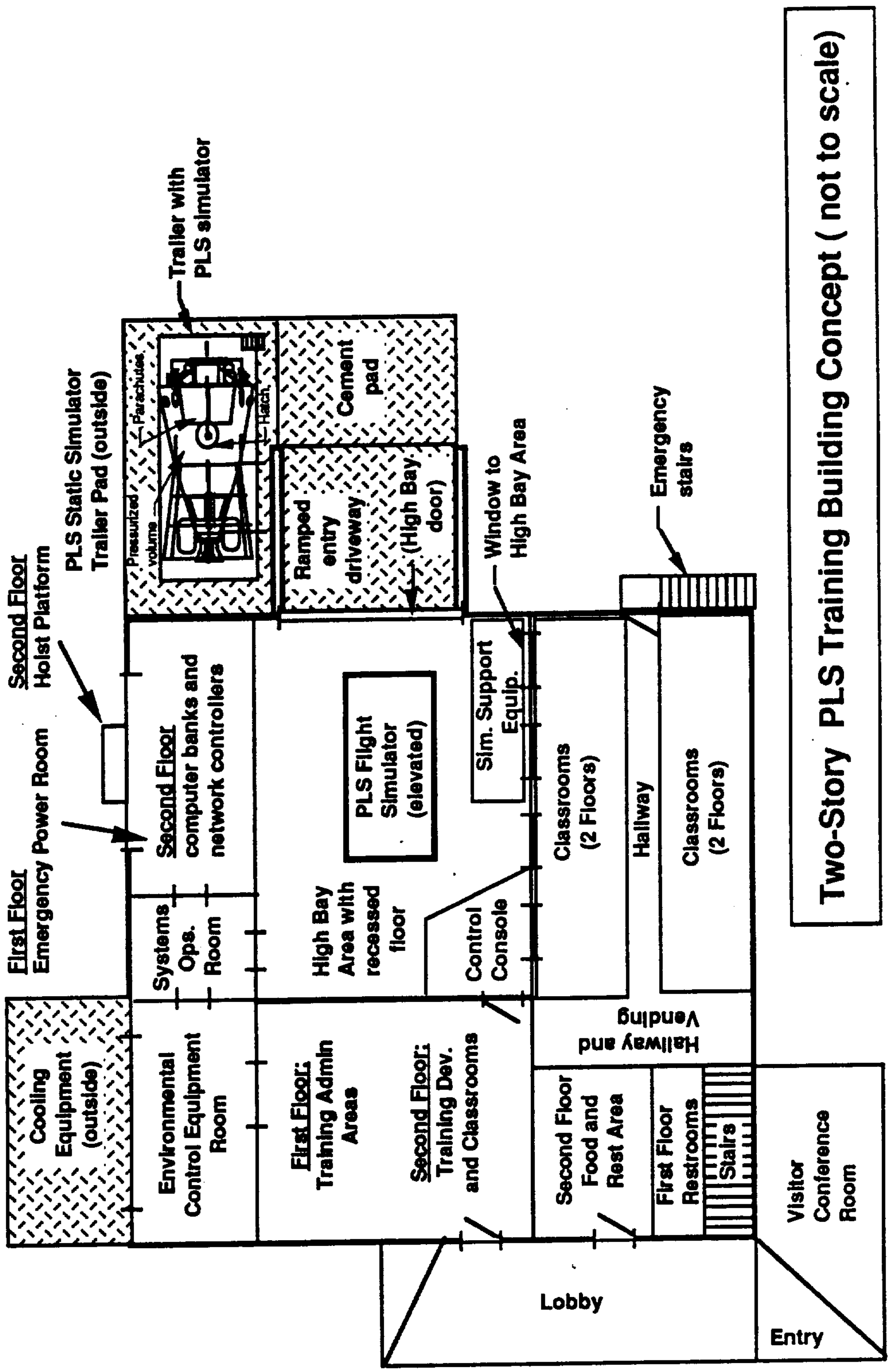


Figure 14.6.2-1 PLS Training Facility Concept

Table 14.6.2-2 Training and Simulators Estimate

PLS Training & Simulator Facility Cost Element	(1989 $ Millions) Estimated Cost	Remarks
Facility Requirements & Plan	$ 3 M	1.7 years effort
Facility A&E Contract	5	2 years effort
Brick & Morter/Bldg. Equip.	4	32,400 sq. feet; 2 story
Computers, Networks, Work Stations, Raised Floors	5	Ground & tempest requirements
HVAC & Process Cooling	2	Est. 200,000 btu/h req.
Auxiliary Power System	1	Computer protection
Tempest Provisioning	3	Excludes lobby/conf. rm.
Security & Fire Protection	1	Access ctrl. required
Subtotal, Building -	$ 25 M	
PLS Flight Simulator (1)	125	Motion & flt. dynamics
Static Crew Simulators (2)	50	1 at JSC; 1 at KSC
Simulator Transporter (2)	1	Special trailers
Audio/Visual Equip./Softw.	1	CAIT's; projectors; etc.
Subtotal, Bldg. & Equip.	$ 202 M	
SE&I Labor Support at JSC	25	Oversees setup & V&V
Total Planning Estimate -	$ 227 M	

Table 14.6.2-3 Mission Control Facility Estimate

PMCC Facility Element	Estimated Value (89$M)
Brick and Morter with Equip. Installation Provisions & Raised Floors (300 x 230 ft.)	$ 9.0 M
Computers & Peripherals, Power	9.0
Furniture, Consoles, Equip.	5.0
Land Lines, Network Interfaces (Fiber Optics)	0.5
Security, Fire Supression, TEMPEST (2 rooms)	1.8
Contingency @ 10%	2.5
Requirements, Planning, & Design (15%)	4.2
Total Estimate -	$ 32.0 M

Table 14.7-1 *Mid-Term Review Cost Per Flight (250 Flights)*

FLIGHT OPERATIONS SCENARIO:

Baseline, Point of Departure Vehicle Performing JSC Mission Model Sorties (Crew Rotation & Satellite Servicing) Between CY2000 -2020.

Life Cycle Cost Element	(21 Years) Average Cost/Flight
Sunken Costs - DDT&E	$ 18.6 M
Facilities Investment	0.4
Production Costs	62.7
Operations & Support	7.0
Booster (ALS) Cost/Flt.	50.0
Total Average Cost/Flight	$ 138.7 M

Total LCC = $ 35 Billion

Or about 1.7 Billion Per Year Cost (in 1989 $) for 21 years service

Table 14.7-? Third Quarter Review Cost Per Flight (250 Flights)

FLIGHT OPERATIONS SCENARIO:

Updated, Point of Departure Vehicle Performing JSC Mission Model Sorties (Crew Rotation & Satellite Servicing) Between CY1999 -2020.

Life Cycle Cost Element	(22 Years) Average Cost/Flight	
Sunken Costs - DDT&E	$ 21.1 M	
Facilities Investment	1.3	Total LCC = $ 41 Billion
Production Costs	53.5	Or about $ 1.9 Billion per year costs (in 1989 $) of service over 22 years
Operations & Support	6.9	
Booster (ALS) Cost/Flt.	80.0	(Revised ALS Cost/Flt.)
Total Average Cost/Flight	$ 162.8 M	

Table 14.7-3 Final DRM 1 Only Cost Per Flight (146 Flights)

REDUCED FLIGHT OPERATIONS SCENARIO:

Final Selection LOX-RP Vehicle Performing Two JSC Mission Model Sorties (Crew Rotation & Lunar/Mars Shuttle) Between CY1999 -2020.

(22 Years Without Satellite Servicing)

Life Cycle Cost Element	Average Cost/Flight	
Sunken Costs - DDT&E	$ 41.1 M	→ Excludes 104 flights
Facilities Investment	2.5	→ Total LCC = $ 32 Billion**
Production Costs	50.9	→ About $ 1.5** Billion per year costs (in 1989 $) of service over 22 years
Operations & Support	38.8**	
Booster (ALS) Cost/Flt.	80.0	→ (ALS cost/flt.)
Total Average Cost/Flight	$ 213.3 M**	At only 8 flt.'s/Year

** Revision A: Correct math error on booster launch support costs calculation & add LES test costs; all other numbers remain the same.

14.8 Trade Studies Support

Two major hardware trade studies have been conducted during the fourth quarter of the study. The first hardware trade study was PLS Orbital Maneuvering System (OMS) reusability. The second trade study concerned the selection of an expendable Launch Escape System (LES). Both LES type (liquid or solid propulsion) and functional operation method (puller or pusher configuration) were traded.

The results of these cost trade support activities are shown in Tables 14.8-1 and 14.8-2. The fully-reusable OMS appeared to be the most attractive, from a development investment cost standpoint (constant-year dollars). The expendable liquid pusher LES for the Boeing POD vehicle configuration appears to be the least cost effective approach. All trades were accomplished using the lowest cost NTO/MMH propulsion vehicle configuration definition.

Cost is only one of several key system selection and evaluation criteria. Safety and technical performance capability have also been assessed to select the optimum orbital maneuvering system (OMS) and launch escape system (LES) concepts. See section 9.3.1 for the OMS and section 10.3 for the LES final selection rationale.

14.9 Final Report LCC Analysis Summary

A summary of the estimates generated during the course of the study is presented in bar chart format as Figure 14.9-1. The bar chart variances are a result of an evolving hardware description, the addition of new facilities estimates and operations and support cost factors, and ALS booster cost estimate updates.

A biconic vehicle will be cost effective to design, build, and transport for a future space transportation system. The biconic structures are less complex and less costly to integrate and maintain than vehicles with higher L/D and less efficient volumetric characteristics. This cost advantage is due to the simpler structural and avionics subsystem interfaces and shapes which are mounted in a more efficient body envelope and thus afford easier hardware access in both the production and operational environments.

The parafoil landing assist technology (without allowance for the proposed redundant backup systems) has been demonstrated by Pioneer Aerospace to be a viable, cost

Table14.8-1 Reusability Cost Trade Summary

(1989 Dollars In Millions - Less all Program Factors)

OMS Config. Option	DDT&E	Production	O & S	Total LCC Delta
Expendable (Ref.):	$ 3,302	9,337	1,745	(Reference)
Design & Dev.	2,989			
Tooling & STE	313			
Partial Reuse Delta:	+ 119	(247)	+ 84	Net= $ 44M Savings (Before Discounting)
Design & Dev.	101			
Tooling & STE	18			
Reuse Delta Est.:	+ 225	(428)	+ 97	Net= $106M Savings (Before Discounting)
Design & Dev.	194			
Tooling & STE	31			

- *Resuse* - shows promise if development costs can be controlled.
- *Partial reuse* - does not show a return on investment.
- *Fully expendable* - estimate contains some qualification risks using unmanned vehicle flight hardware for manned space applications.

Table 14.8-2 LES Cost Trade Study Results

	LAUNCH ESCAPE SYSTEM TRADE SUMMARY BY CONFIGURATION 1989 DOLLARS IN MILLIONS					
	Pointed End Forward			Pointed End Aft		
OPTION	Solid Tractor	Solid Pusher	Liquid Pusher	Solid Tractor(POD)	Solid Pusher	Liquid Pusher
DEVELOPMENT COST						
DESIGN & DEV. (+SUPPORT LABOR)	357.1	249.7	143.2	441.2	323	202.5
TOOLING	8.5	7.8	11.2	9.3	8.9	9
TEST HDWR (TFU x QTY) + INITIAL SPARES	300.3	277.2	385	325.6	312.4	316.8
(DEV QUAN-11 EQUIVALENT UNITS)						
TOTAL PHASE C/D (DDT&E)	665.9	534.7	539.4	776.1	644.3	528.3
PRODUCTION COST						
TFU HARDWARE	26.6	24.6	34.1	28.8	27.7	28.1
PSE ALLOTMENT (MFG. ONLY)	1.3	1.2	1.6	1.4	1.3	1.3
TASK DIRECT QA.	2.9	2.7	3.7	3.1	3	3.1
LIAISON ENGINEERING	16	10.1	4.9	20.8	14.1	7.7
SPARES (REPLENISHMENT)	0.7	0.6	0.9	0.8	0.7	0.7
DATA	7.7	5.3	3	9.6	7	4.3
TOTAL #1 COST ($M)	55.2	44.5	48.2	64.5	53.8	45.2
CUM FACTOR FOR 90%	127.78	127.78	127.78	127.78	127.78	127.78
TOTAL PRODUCTION COST	7053.3	5686.1	6158.9	8241.7	6874.4	5775.5
ACQUISITION COST	7719.2	6220.8	6698.3	9017.8	7518.7	6303.8
GROUNDRULES						
1. Expendable system options only						
2. Use IUS spares average of 3%						
3. Assume 250+2 production deliverables						9/10/90

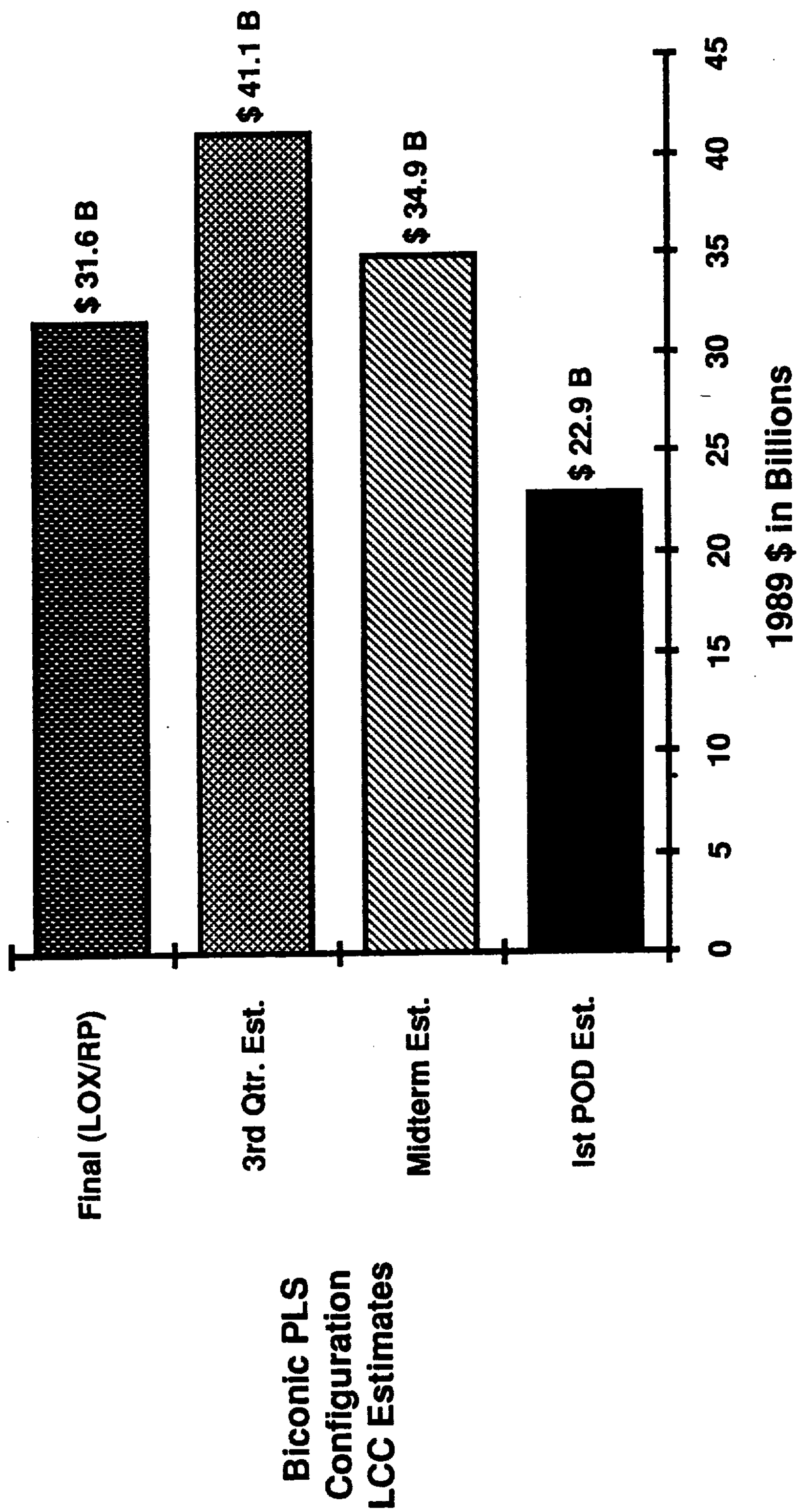


Figure 14.9-1 PLS LCC Estimates Evolution

effective option for vehicle landing at reasonable cross range requirements and reduced speed final approaches. There is some technical and cost risk in the expanded parafoil development testing, but the rewards of lower landing speeds and simpler vehicle design may outweigh the bias toward a more traditional winged design.

15 GROWTH AND EVOLUTIONARY MISSIONS

There are several possible paths for PLS evolution. To help in understanding the differences, possible options were categorized by function and destination. The functions were manned delivery and/or servicing. Possible destinations are LEO, GEO, cis-lunar, and beyond. Each category is discussed in depth in the following sections.

15.1 LEO Growth Missions

SSF Crew Rotation - DRM 1 for PLS was specified as the SSF crew rotation mission. This is nominally a three day mission in which the PLS remains docked to SSF, long enough only for the new crew to familiarize themselves with the on-going SSF mission, and then departs with the old crew. A possible growth mission (originally listed as DRM 2 in the SOW) would be for the PLS to remain docked to SSF during the entire crew stay and thereby be available for emergency departure. At the end of each crew rotation, a new PLS and crew are launched and after a minimum overlap period, the old crew returns to base in their original PLS. This is the same system used by the USSR (Salyut and Mir) and similar to Apollo-Skylab.

The advantages of this technique include crew familiarization and security with the vehicle they flew up in, and the need to develop only one vehicle type to support permanent manning of SSF. The disadvantages are the six month stay time on orbit which will require changes to a few of the PLS subsystems. The principal changes would be in the OMS, where a storable oxidizer would be substituted, and the EPS, where batteries with a small solar panel would insure an autonomous, constantly ready power supply. Other subsystems would need to be carefully scrutinized to address concerns with reliable restart after a dormant period.

LEO Manned Servicing - There are two types of manned servicing in LEO; scheduled/unscheduled satellite servicing, and man-tended operations of LEO processing satellites. The satellite servicing missions would be equivalent to servicing of the Hubble Space Telescope. This would require rendezvous and grappling/docking with a passive spacecraft, changeout of failed or obsolete components, and refueling of the spacecraft. Maneuvers in the vicinity of the serviced satellite must be non-contaminating and nondestructive. This mission will definitely happen but it's frequency is extremely hard to estimate with any accuracy. Requirements for this mission are: a grappling arm, remote manipulator arm(s), and

most likely an airlock and complete EVA supplies for two astronauts. The specific items were discussed in section 9.10. This mission is a PLS design driver because of the required, bulky mission equipment.

The mantended operations of the LEO materials processors could be a NASA mission or a commercial venture. This mission differs from SSF crew rotation in that the personnel compliment would be two pilots and two or three operators and raw materials would be carried. If five personnel are carried, then 1500 pounds of raw materials could travel inside the PLS and be exchanged for 1500 pounds of processed materials using IVA. If more materials are required, a mini-module weighing about 20,000 lbm could accompany the PLS on a 1.5 stage ALS. This module could be berthed at the processing facility in the manner shown in Figure 15.1-1 to provide additional raw materials. Unfortunately, this would be a one way trip for the mini module because the return payload, in addition to personnel, is limited by the design landing weight to about 1500 lbs. The stay time at the processing facility is limited to one to two weeks for the baseline PLS because of the onboard cryogens. A long duration PLS would be identical to that mentioned for six month stays at SSF. Note too that a heavy lift launch vehicle, such as an ALS 2 stage concept, would possess sufficient performance to launch a SSF logistics module in addition to the PLS (see Figure 15.1-2).

Given the rate of advance in advanced materials processing technology seen in Japanese and European journals, mantended material processing is a very likely PLS mission which will probably be contemporary with SSF and grow rapidly in frequency.

LEO Rescue - A key design driver for the current baseline PLS configuration was the necessity to carry a large assortment of berthing and docking modules to enable rescue from various manned spacecraft projected to be in use by the year 2000 (i.e. SSF, Mir, STS Orbiter, Buran, Hermes, etc.). The need to maneuver in tight places and adequate clearances to allow berthing also constrained the size and shape for the working end of the baseline PLS. Clearances are adequate to allow the PLS to berth to any port on SSF, not just the shuttle docking ports (see Section 9.10).

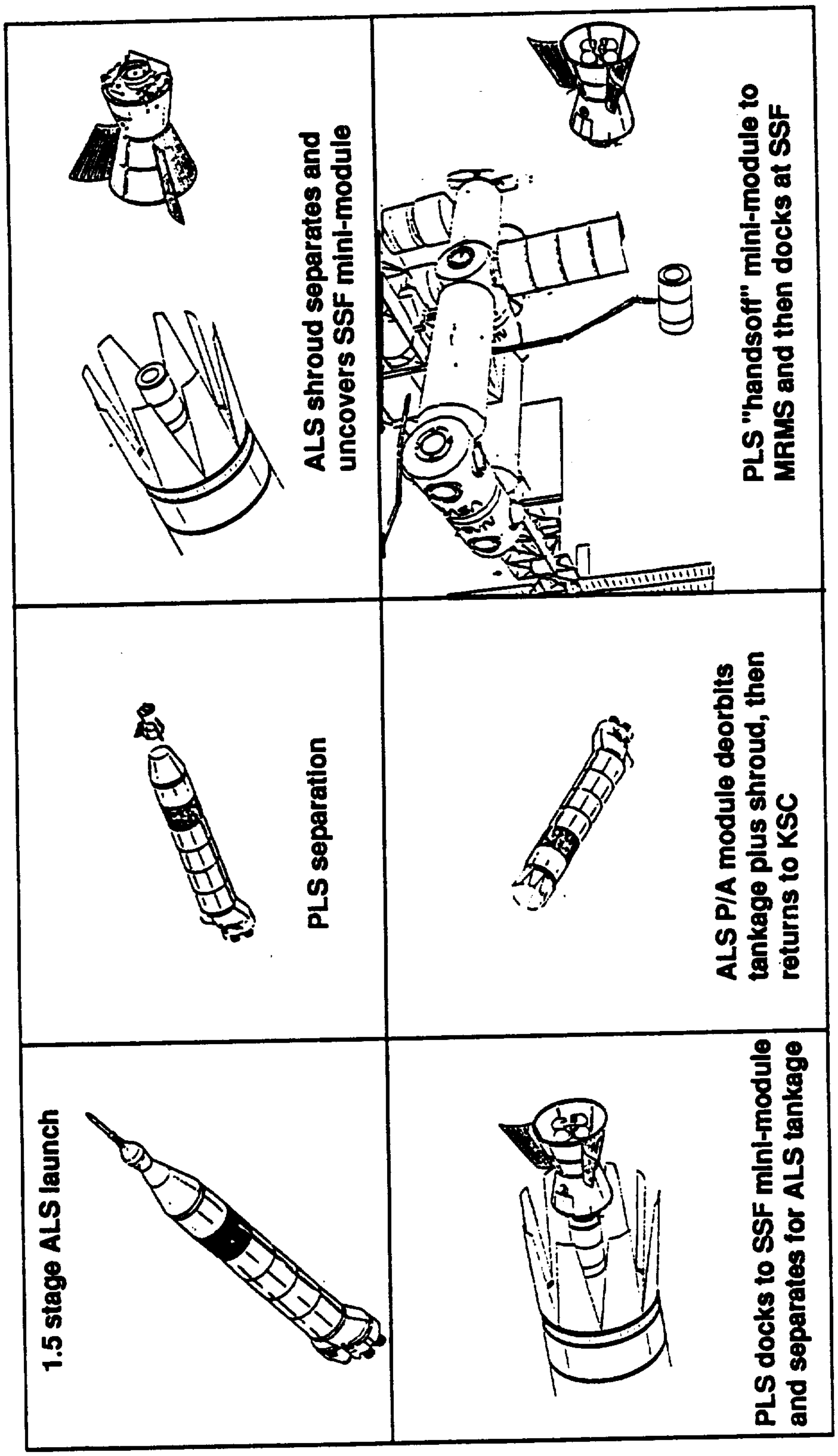


Figure 15.1-1 PLS Delivery of Mini Materials Module

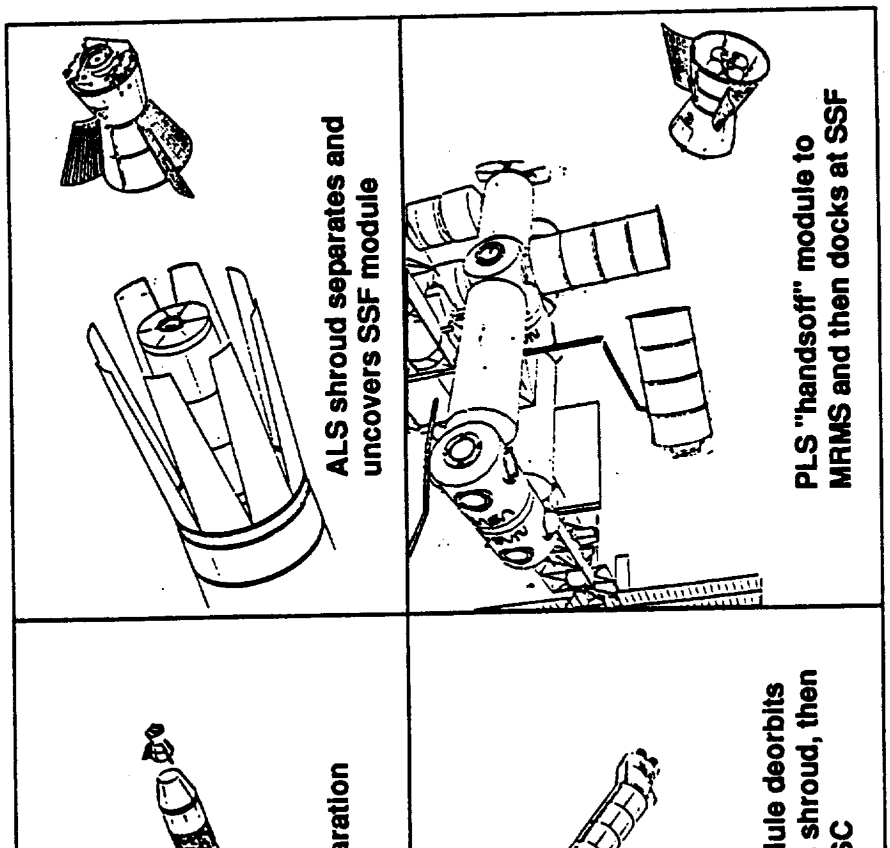


Figure 15.1-2 PLS Delivery of SSF Logistics Module

15.2 GEO Growth Missions

GEO Crew Rotation - Manned GEO observation posts have been proposed for years. GEO is a secure location for observation, command, and control functions. The necessity for secure, well equipped observation posts will become increasingly important as the world reduces the amount of nuclear offensive capability and backs away from Mutual Assured Destruction (MAD) as a defensive strategy. Hence, it is likely that manned GEO missions could again become part of DoD strategy.

The PLS would be an ideal vehicle for GEO crew exchange. A TPS upgrade would be required, either low density ablator or transpiration cooling on the nosecap and forebody, but those technologies are already in use elsewhere. A semi-reusable Main Propulsion System (MPS) of the type shown in Figure 15.2-1 would also be required. The entire package, PLS and MPS, would be launched, fully integrated on a two-stage ALS, into a suborbital trajectory. The PLS + MPS would perform a direct burn into GEO transfer orbit and immediately jettison two drop tanks which would circle past GEO and burn up on earth reentry. The PLS + MPS would circularize in GEO, rendezvous with the GEO outpost, dock with the manned module, and transfer crews.

The return scenario is more complex. After departing the GEO outpost, the PLS + MPS would effect a small plane change and phasing orbit burn for positioning at the proper latitude and time for a deorbit burn (see Figure 15.2-2). At the proper time, a deorbit burn would be made such that the latitude, longitude, and inclination at perigee allows a lift vector down trajectory ending over KSC. The phasing maneuver takes a maximum of 18 hours and the atmospheric grazing transfer requires 6 hours, so return opportunities occur at least once a day.

GEO Servicing - Manned servicing of communication platforms was a standard NASA upper stage mission for years. Unfortunately, technology and economics have driven the commercial operators away from large multipurpose platforms into smaller specialized spacecraft with long lives and planned obsolescence. By the time the spacecraft is worn out, it's obsolete anyway, and needs to be replaced with a new model, not updated. Also, at the higher frequencies and power levels now in use, interference between closely spaced antennas operating at different frequencies becomes a problem. However, the opportunities for direct broadcast of high resolution TV and global personal communication may revitalize the large platform concept. With

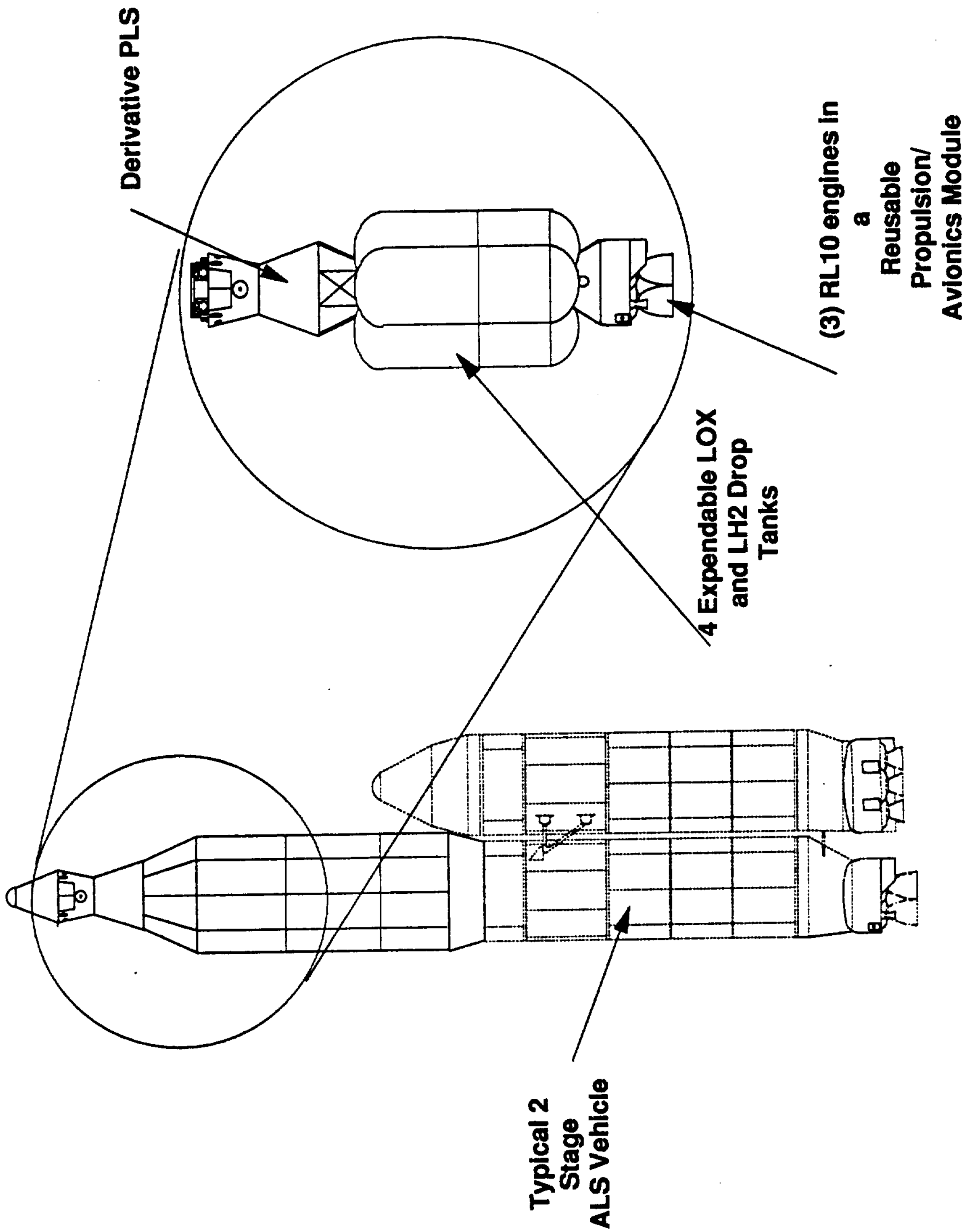


Figure 15.2-1 PLS GEO Mission Vehicle With MPS

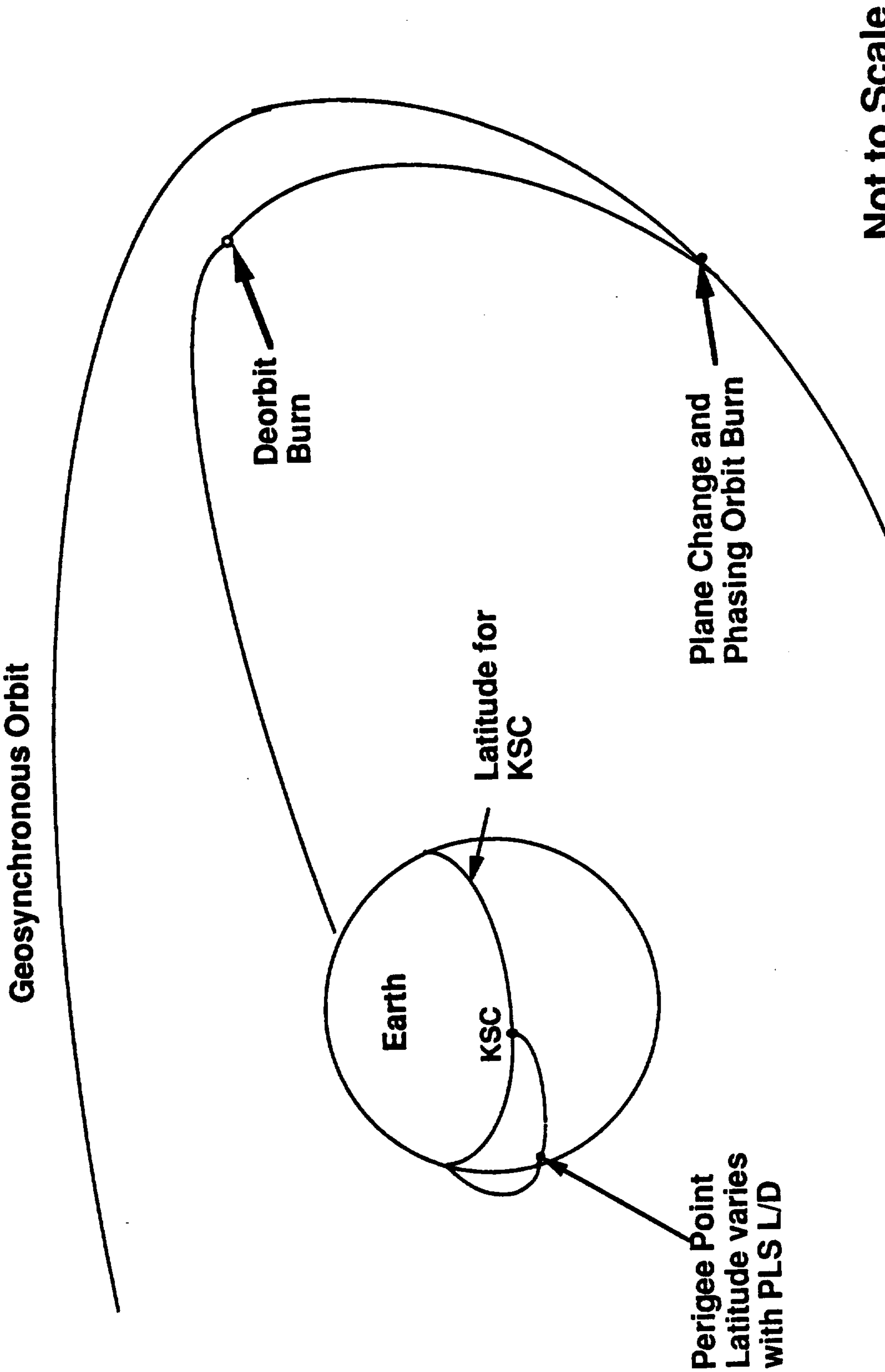


Figure 15.2-2 PLS GEO Mission Trajectory

large high power specialized platforms in operation, the concept of manned GEO servicing might well become economically feasible.

In practice the scenario for manned GEO servicing would be very similar to that for GEO crew rotation. Most likely a Manned GEO Service Station (MGSS) would be deployed near GEO, and used as a base of operations to service multiple platforms at different longitudes. A version of the MGSS created during NASA OTV studies is shown as Figure 15.2-3.

15.3 Space Exploration Initiative Missions

Lunar Crew Rotation - A manned Lunar outpost is the first step in the President's Space Exploration Initiative (SEI). Crew rotation will take place on an annual or semi-annual basis. The PLS could be used as the crew transit cab and also as the lunar crew module if a lunar direct scenario is selected (everything goes to the lunar surface and nothing is left in Low Lunar Orbit). An example stage and a half lunar direct vehicle utilizing a PLS derived Crew Module is shown in Figure 15.3-1.

The advantage of a PLS derived Crew Module is the capability to return directly to the launch site at any time. Return opportunities to SSF occur only once every eight days because of precessing of the SSF orbit. Return opportunities to KSC are continuous and only require variations in the trans Earth injection burn to vary the transit time in order to position KSC at the right point for landing. The mid course correction varies the azimuthal direction to line up KSC with the perigee point as shown in Figure 15.3-2.

Improved radiation protection and TPS will be required for the lunar mission. The two needs could be combined if extra water is carried for radiation shielding and then used for transpiration cooling during reentry. Initial investigations of transpiration cooling as a method to improve the robustness of the PLS TPS and reduce maintenance costs showed potential application to higher energy missions as well.

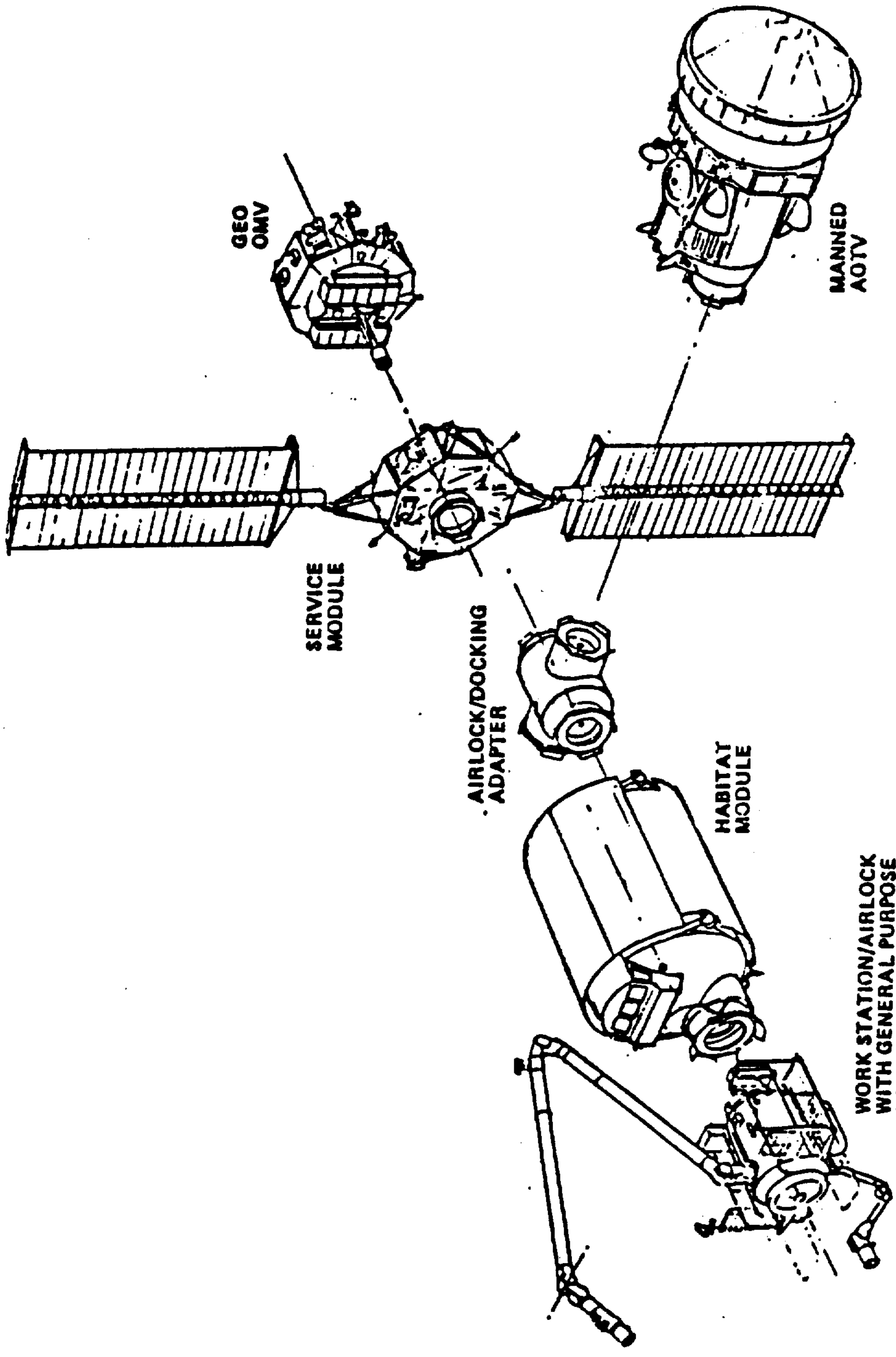


Figure 15.2-3 Manned GEO Service Station (MGSS) Concept

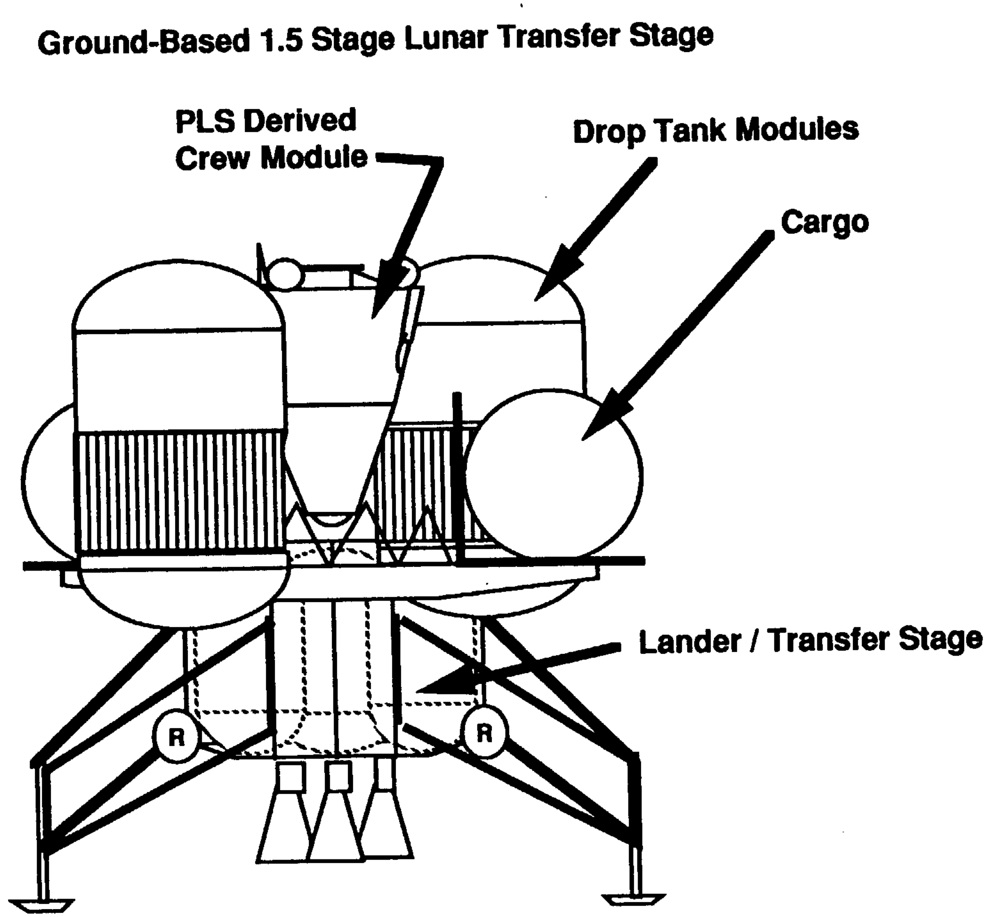


Figure 15.3-1 PLS Derived Crew Module For Lunar Transfer Mission

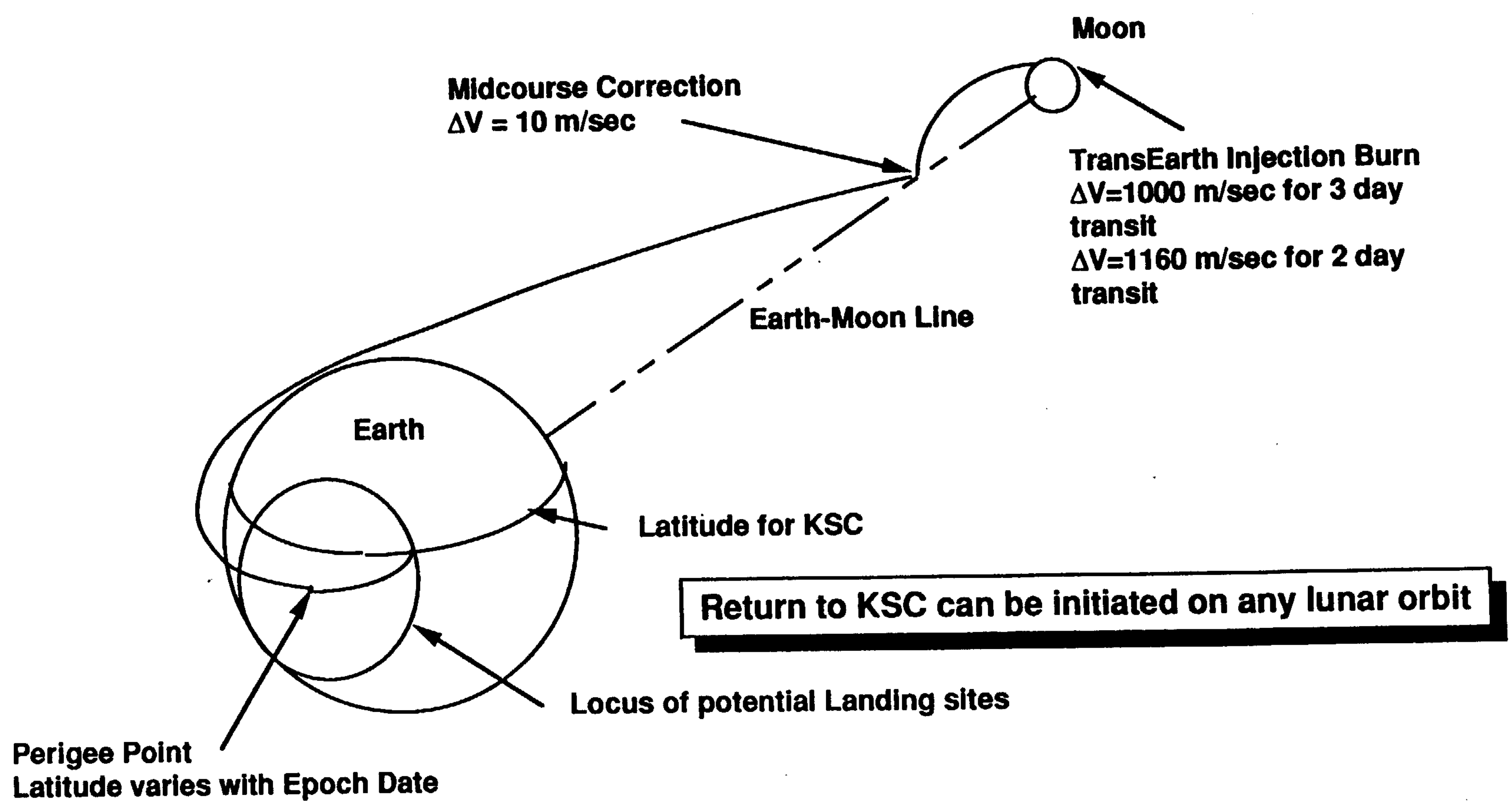


Figure 15.3-2 Lunar Return Trajectory

Mars Crew Return Capsule - Most scenarios of Mars exploration missions require a small manned capsule to return the crew to the Earth's surface. Assuming a crew of six to eight plus valuable samples, the use of a PLS derivative seems straight forward. This could be the highest energy reentry ever performed and use of ablators or transpiration cooling would be essential. The chief advantage of PLS would be its ability to return the astronauts directly to the ground using moderate g-levels. Key issues would be the viability of TPS and parachutes after two to three years in interplanetary space.

16 TECHNOLOGY ASSESSMENT/RECOMMENDATIONS

The design of the PLS, as constrained by the given groundrules, almost exclusively utilizes existing technology. By selecting a 1992 TAD, a short development cycle could be foreseen that would support early SSF operations. In addition, subsystem cost, reliability, and ultimately, safety would benefit if near-term technologies are used.

There are several areas of recommended technology development that could positively affect the program objectives of enhanced operability, cost performance and safety. These recommendations can be made both at the system and subsystem levels. The following paragraphs discuss these recommendations independent of priorities or cost implications.

Launch Vehicle - A new, PLS unique launch system, or an ALS, would provide for safe (probably all-liquid with engine-out capability), operationally efficient launch operations. Starting with a new launch vehicle enables the system to be optimized for manned operations and could lower upfront costs by combined development with the PLS. Design for operability will also significantly reduce the current "standing army" problem, thus reducing costs considerably. The ALS, currently the most likely candidate for a new US booster, incorporates many desirable features for PLS, such as:

- initial adequate margins to enable a low risk (probably heavier) PLS design,
- modular family of vehicles to provide PLS evolutionary growth potential,
- all-liquid propulsion to provide sufficient time for abort/crew escape, and,
- a high reliability approach so as to be inherently supportive of man-rating (engine-out capability, quad string avionics, etc).

Autonomy - As mentioned in the SOW, it was intended that the PLS would eventually be an autonomous vehicle. For the initial phase of operations, the design currently includes two pilot-astronauts. While computing hardware can be extrapolated to support the goal of autonomy, other changes must be made to enable implementation of full autonomy:

- GPS (or equivalent) working in conjunction with fast adaptive guidance algorithms must be in place,
- flight support, equivalent to the Air Traffic Control system, is required for rendezvous scheduling and collision avoidance,
- ground support (simulator facilities on standby) will still be needed to cope with emergency situations,
- standardized missions reduce the requirement for extensive preflight planning and checking, and,
- "crew" members must be trained in a variety of disciplines (orbital mechanics, subsystems, etc.) to have the ability to assess and/or correct automatic systems when errors do occur.

Recovery Method - While many options exist, and indeed have flown, for the deceleration/recovery/landing phase of the flight, some of the choices must be made on perceived risk. Pilot decision time during final approach and limited cross wind capability of runway landing concepts may not be justified by the operational benefits of landing at an "airport". While parachute technology is mature, wind dispersions upon landing may require large landing areas that are obstacle free. The selection of parafoil technology addresses the following issues:

- Abort (successful water "ditching" requires impact velocities of less than 80 kts),
- Landing Site Preparation (for a nominal landing on a relatively unprepared surface, or for a land abort, the ability to perform terminal obstacle avoidance maneuvers translates to improved safety),

- Impact Attenuation (the ability to aerodynamically flair and reduce vertical velocity using the existing control system can significantly reduce the mass and complexity of other impact attenuation hardware), and,

- All Weather Operating Capability (in the absence of a runway orientation, cross wind limitations are moot; also, the forward velocity capability of a parafoil can be used to negate high, 95th percentile, ground winds).

The current MSFC ARS program, with Pioneer Aerospace as the prime contractor, has been developing large scale parafoil technology that is directly applicable to a PLS sized vehicle. Continuation of this program is encouraged as a NASA initiative to provide sufficient data for evaluation of this extremely promising technology.

Subsystems - Several new technologies are "on the horizon" that could improve the PLS, but would not be available to support a near term IOC. The following paragraphs describe the most promising technologies for further study.

Propulsion - the selection of reduced hazard propellants, such as RP, ethanol, hydrogen peroxide, etc. are all conceivable as options to improve safety and operability. Currently, SSF and NASP are exploring hydrogen/oxygen technology for RCS use. In time, the issues of acquisition, scavenging, and ignition will be resolved. An OMS/RCS/proximity operations (H_2) system using only two separate fluids is extremely attractive operationally.

Electrical Power - battery storage systems continue to improve with time although their use as a primary power source is still projected to be limited due to weight concerns. Fuel cell technology has also improved substantially from earlier space systems, but will remain more complex than batteries. If volume for reactant storage becomes an issue, alkaline metal hydrides (such as LiH or CaH_2) offer a potential alternative to hydrogen. Solar photovoltaic cells have seen tremendous gains in efficiencies and are an excellent choice for on-orbit applications when used in connection with a rechargeable battery assembly. The NASP program is developing hydrogen/oxygen auxiliary power unit (APU) technology that could also be used. The ideal PLS solution would probably look like one suggested by Figure 16.0-1 where a solar array/battery would provide on-orbit power while a hydrogen/ oxygen APU would provide for the

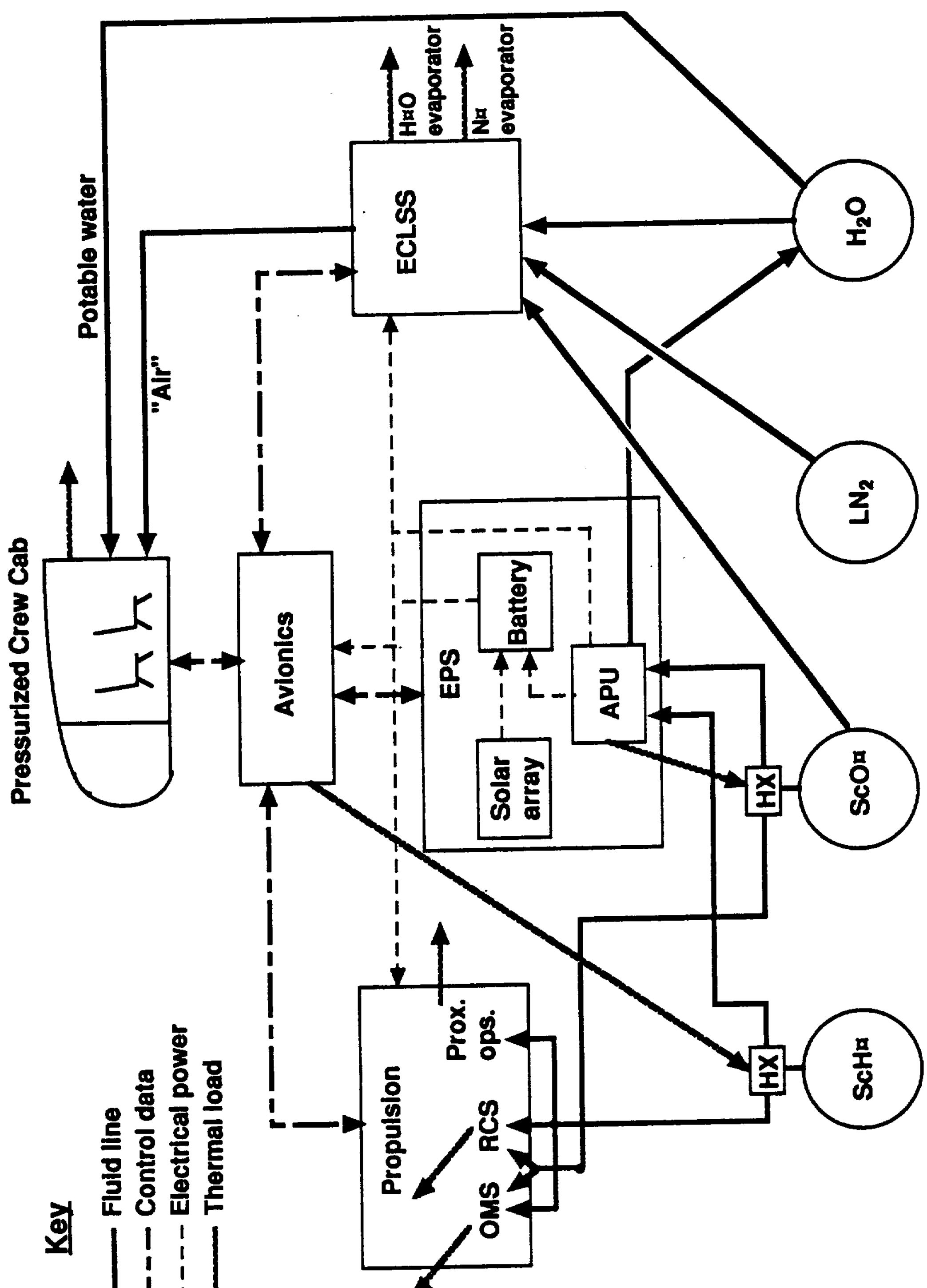


Figure 16.0-1 Idealized PLS Systems Schematic ~ TAD Circa 2000

shorter duration, higher peak loads during ascent and descent. This would minimize the number of fluids used on board.

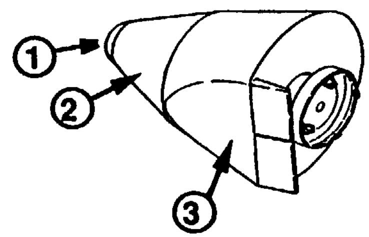
<u>ECLSS</u> - as our cumulative time in space increases, the United States is sure to improve upon life support technologies. Present day technology appears adequate for all the PLS DRMs. Evolutionary missions may require longer duration missions, in which case regenerative systems may be warranted. Such systems would be used, for example, to filter CO_2 through a reusable membrane, or to recycle metabolic wastes for additional water. Waste heat rejection options were discussed in Section 9.7.3. The simplified system shown in Figure 16.0-1 includes a nitrogen (or hydrogen) flash evaporator, as well as local heat sinks (such as an avionics bay), used in conjunction with heat exchangers associated with the use of supercritical fluids (H_2 and O_2).

<u>Avionics</u> - advancements in avionics hardware are almost second nature. Most requirements that a PLS would have will be met by the demands of other programs. If there is a sub-technology to promote for PLS avionics, it would be cold-plate cooling. The elimination of integral liquid cooling loops or air cooling would simplify maintainability.

<u>Software</u> - development of advanced programming languages, techniques, and algorithms would provide benefits but are not always included in technology planning. In particular, adaptive guidance schemes that permit real time on-board mission planning would provide for unprecendented contingency planning and operational flexibility without the penalty of large software support staffs. Modern techniques such as artificial intelligence, expert systems, fuzzy logic, and virtual reality all have a place in an efficient PLS design.

<u>Structures/TPS</u> - when taken together as an integrated system, the choice of structural and thermal protection concept can significantly influence the ground turnaround time. The key attribute of successful aerospace vehicle structures has been robustness. In this regard, robustness may be defined as the ability to perform reliably with a minimum of inspection and maintenance.

In the recent past, there has been a resurgence of interest related to robust hot structural materials, especially in conjunction with the NASP. Whether the NASP program eventually attains the goal of a single stage to orbit may be in question; regardless, there is a large and growing database of materials that would be applicable to a PLS. Taken by themselves, many of these high temperature materials could be used on the "cooler" sides and top of the vehicle, away from the stagnation regions, without requiring special treatment, coatings, or adhesives. In the hottest regions of the PLS surface, some form of "active" cooling would be required. At first, active cooling is often dismissed as complex, heavy, and inconsistent with manned safety should a failure occur in the fluid flow system. The PLS is exposed to the highest temperatures for a realatively brief period, enabling the use of some different cooling strategies as compared to a hypersonic cruising vehicle which spends a much longer time at high temperatures. One such strategy is shown in Figure 16.0-2. A perforated titanium skin is backed by an insulating layer of cork. A small amount of water is circulated into a honeycombed structural layer and wets the cork. As the temperature in the cavity rises, the formation of steam removes heat by "leaking" through the outer skin. This transpiration cooling is extremely simple and effective. In the event of a disruption of the water flow due to some failure, the skin would char away and the cork would ablate, leaving the inner structure unharmed. There are other techniques for using these advanced materials that should also be explored.



Coolant Required(lbs H_2O)

Loc	Backwall cooling only	Backwall + Transpiration
1	371	93
2	735	184
3	748	187
total	1854	464

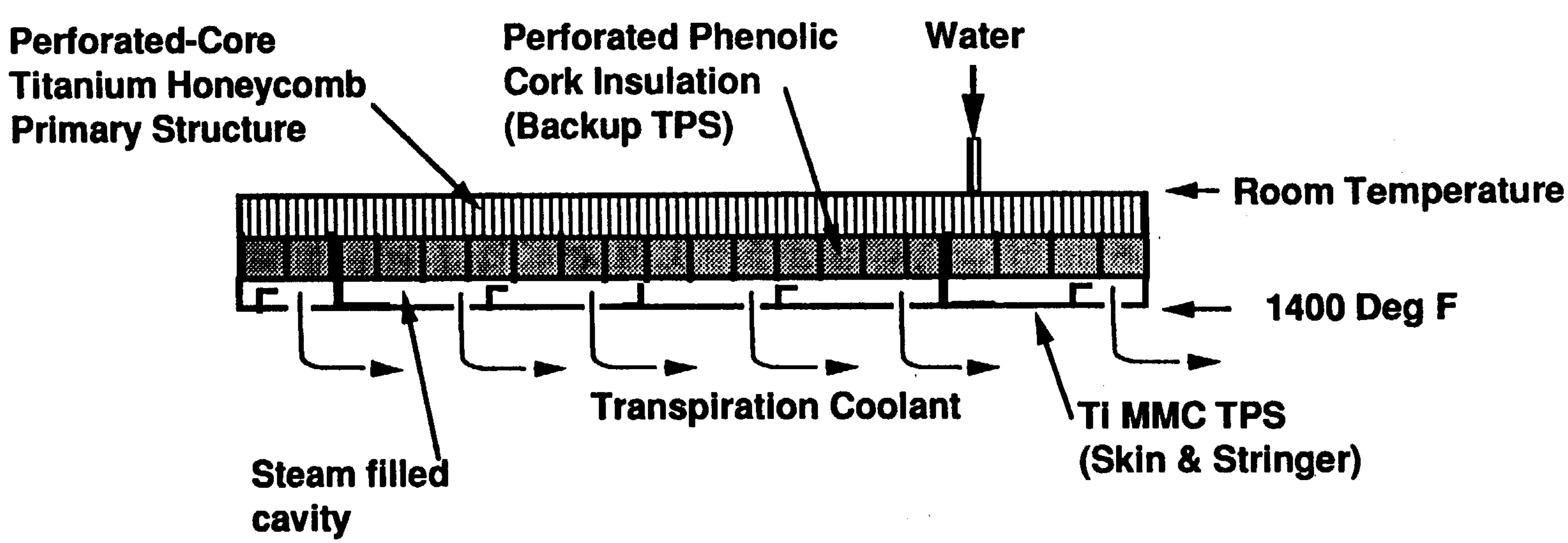


Figure 16.0-2 Transpiration Cooled TPS Concept

17 SUMMARY/CONCLUSIONS

This report has described a conceptual design for a non-winged, Personnel Launch System designed to safely transport up to 10 people to and from Earth orbit. The preferred concept is a biconic shaped design that is launched on an ALS (or equivalent) launch vehicle and is capable of performing a variety of manned missions. Sufficient growth capability is provided to ensure the usefulness of the PLS for many years to come.

A drawing showing the external features of the biconic design is shown in Figure 17.0-1. The vehicle was also rendered in three dimensions (seen in Figures 17.0-2 and 17.0-3) using computer aided solid modelling software, primarily to assure sufficient volume and access for subsystems. Figure 17.0-4 is a summary datasheet of the configuration.

This conceptual design study has shown that a "no wings, low L/D" PLS can be designed that fully meets the program's objectives. Safe, efficient manned transportation to and from LEO is possible using largely existing technology, and the system is capable of growth to meet a range of future mission requirements.

The lessons of Design for Safety, Design to Cost, and Design for Operability are well understood in the aircraft world, and many of these lessons can and should be applied to the design of the PLS. Operations costs, in particular, will continue to dominate the system costs. The PLS, with its small physical size and near-term technology level should be inherently less expensive to operate than current manned spacecraft. Additionally, the possibility exists for dramatic reductions in operating costs through emulation of the safe and successful operations of commercial airlines.

Selective use of some new or developing technologies would greatly enhance some aspects of the PLS. Many of these recommended technologies, such as parafoils, hot metal TPS, etc. are applicable to a number of other aerospace vehicles. Coordination of planning by NASA, the DoD, and industry should enable these technology developments to proceed, even in an era of declining budgets.

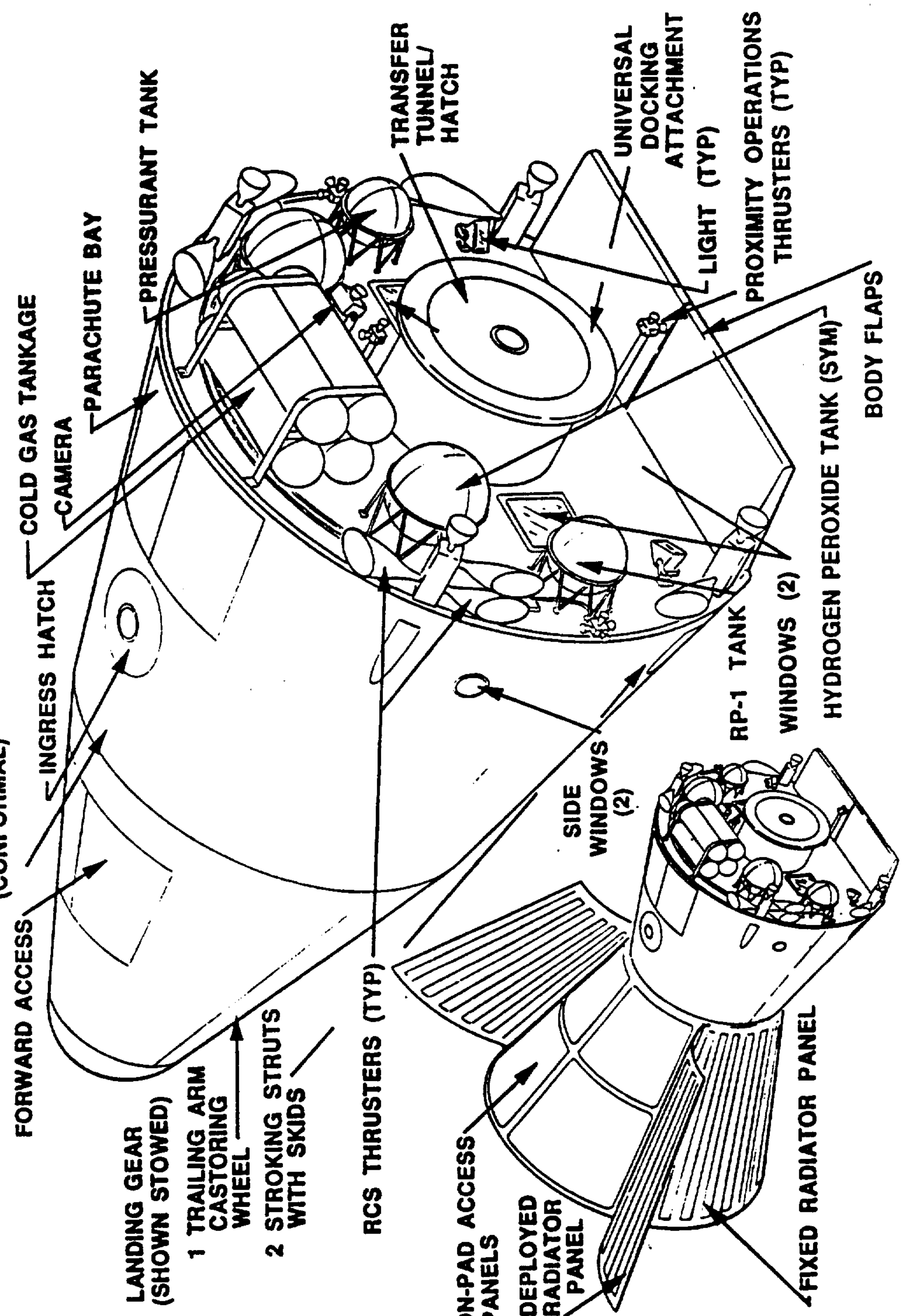


Figure 17.0-1 PLS Exterior Features

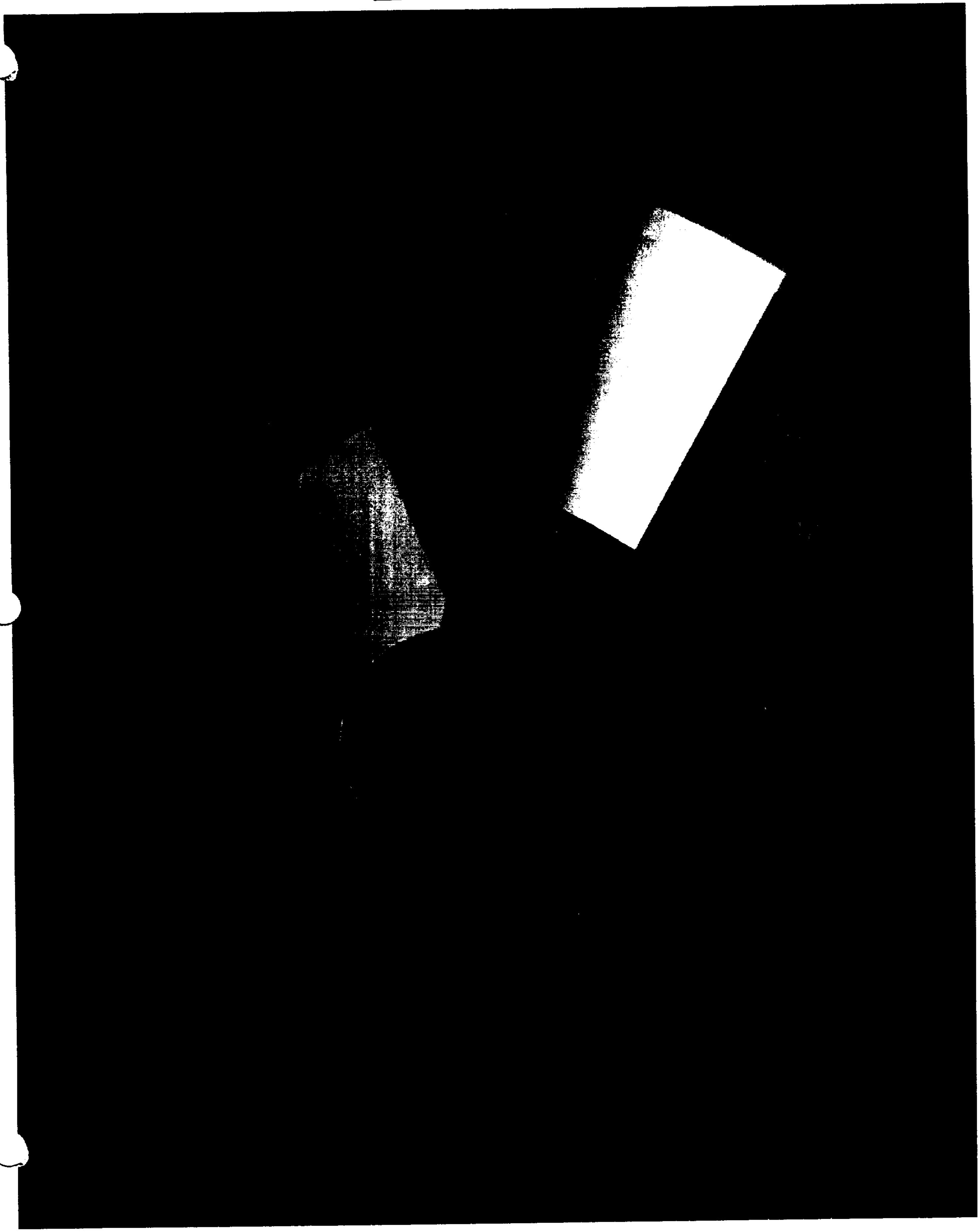


Figure 17.0-2 PLS Solid Model

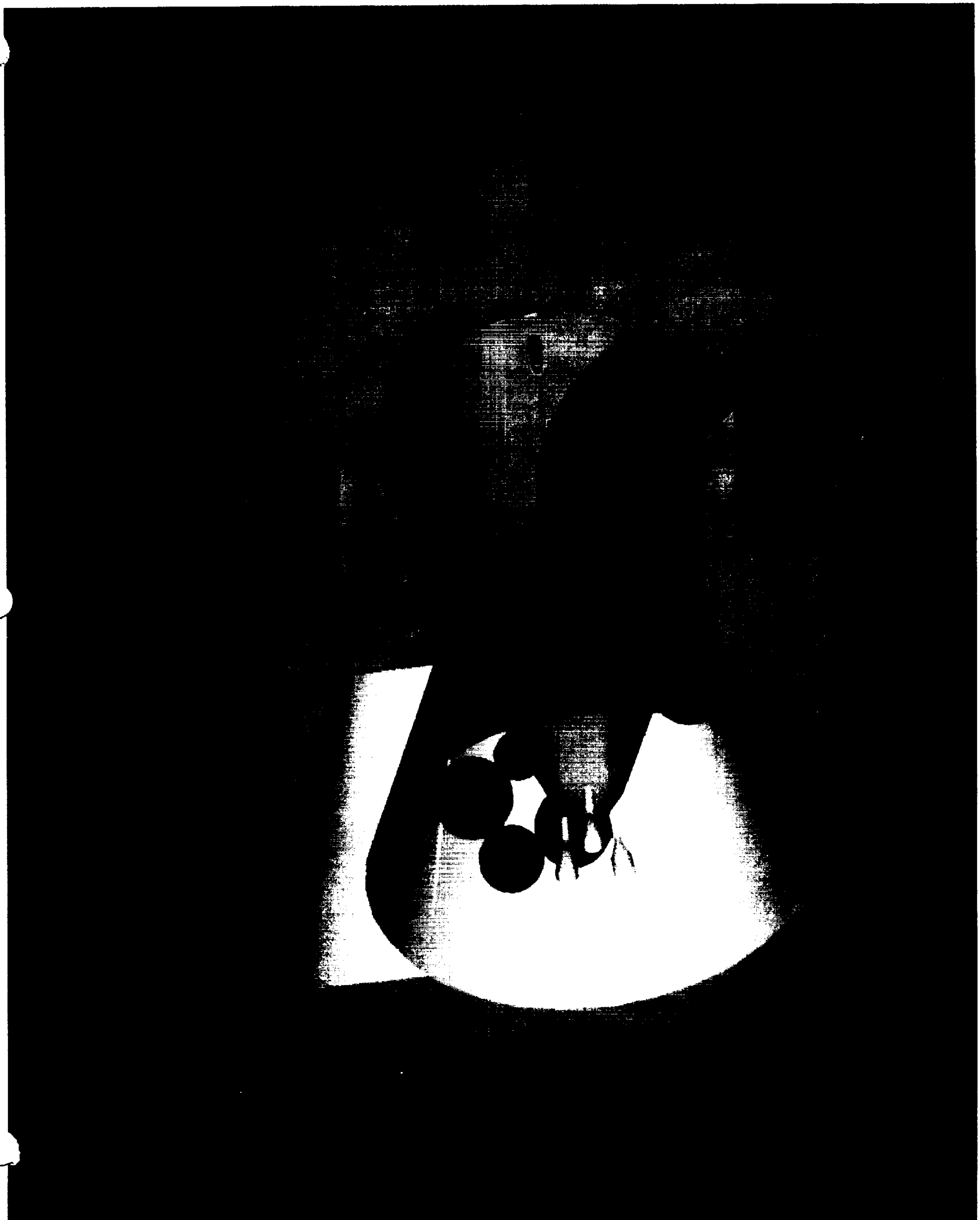


Figure 17.0-3 PLS Solid Model, Alternate View

This study did not include a definition of the PLS launch vehicle, however, the cost of launch vehicles and launch services is a major element in the PLS life cycle cost. A new, safe, and efficient launch vehicle, such as the ALS (currently under development) is recommended to be integrally included in PLS program planning.

In the commercial aviation world, accurate prediction of future traffic levels and missions is of paramount importance. Likewise, the realization of an affordable, efficient PLS will depend on an unbiased assessment of the future needs for manned space transportation. In the period this contract was conducted, an exciting new, peaceful international climate is emerging. Identifying other international users for a PLS, such as the European Space Agency, Japan, China, the USSR, or even private companies, could reduce the cost of the individual vehicles. The relatively low technology level of a PLS should present few "technology transfer" questions. Also, the use of an alternative launch vehicle or launch site could result in the lowest possible costs to the user.

In summary, our nation is on the threshold of a new era in manned space transportation where access to low Earth orbit can be considered routine. The PLS is the system that can enable the realization of that next step in space travel.

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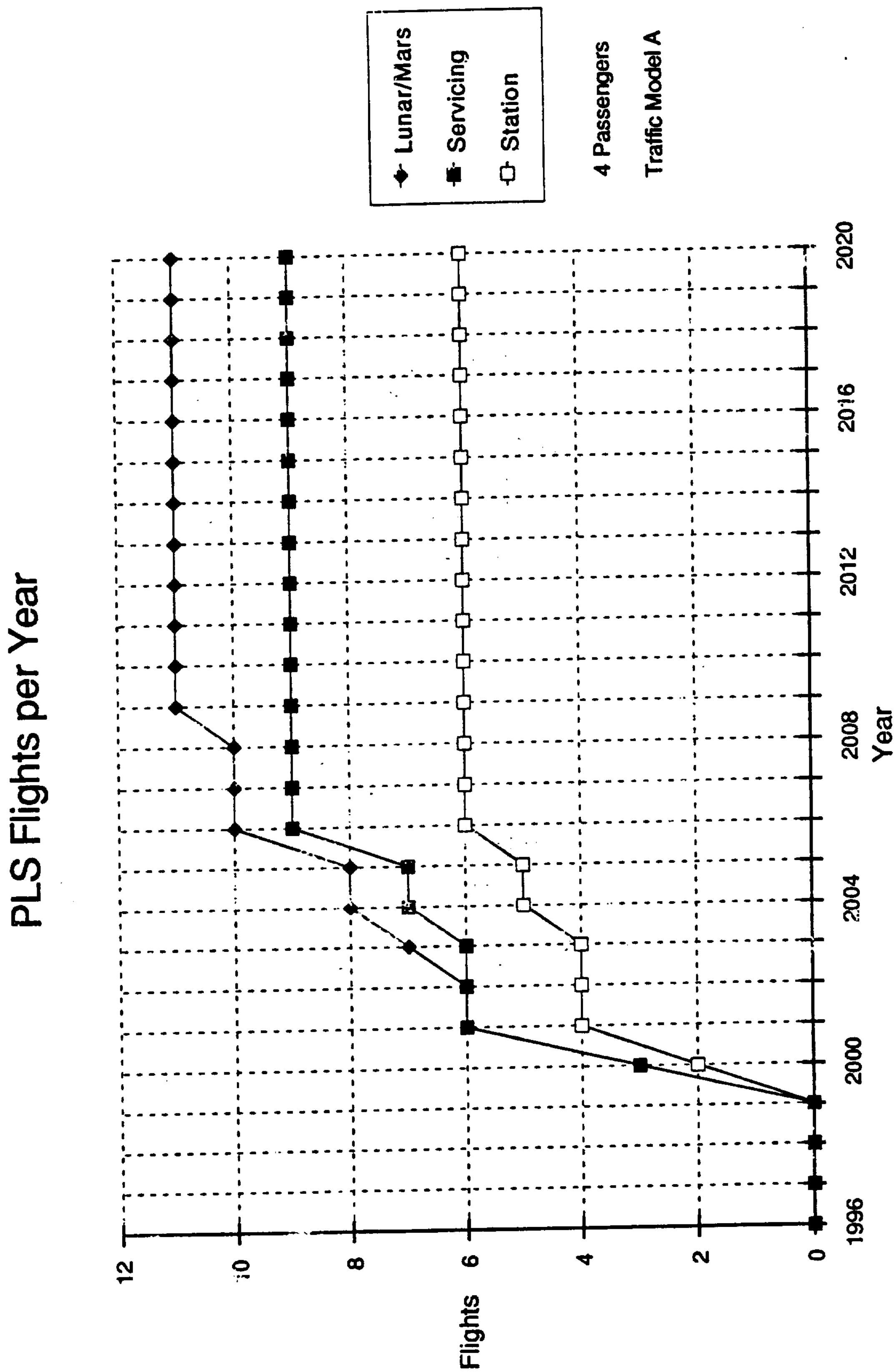
PLS Flights per Year
Lunar/Mars
Servicing
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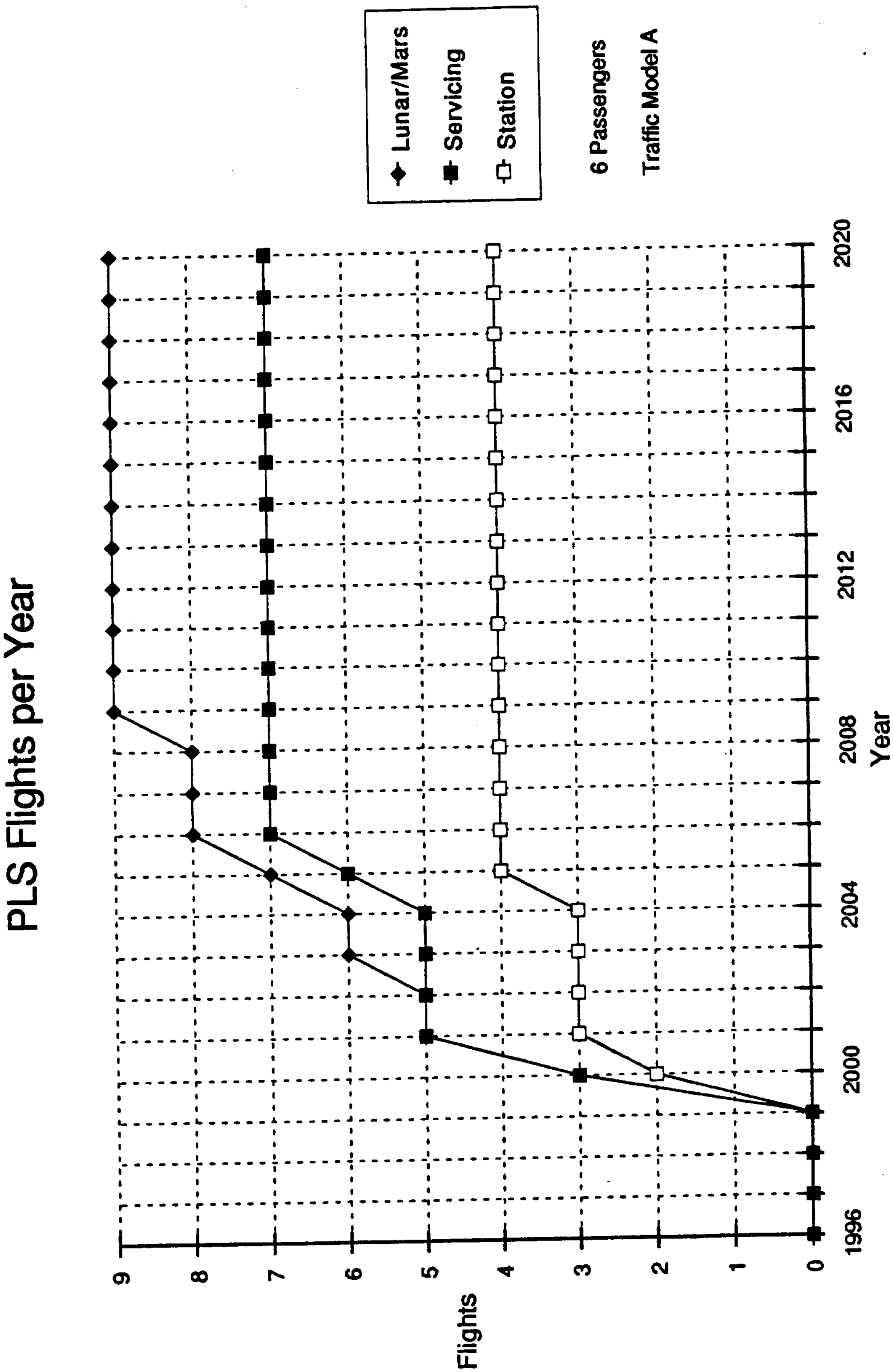
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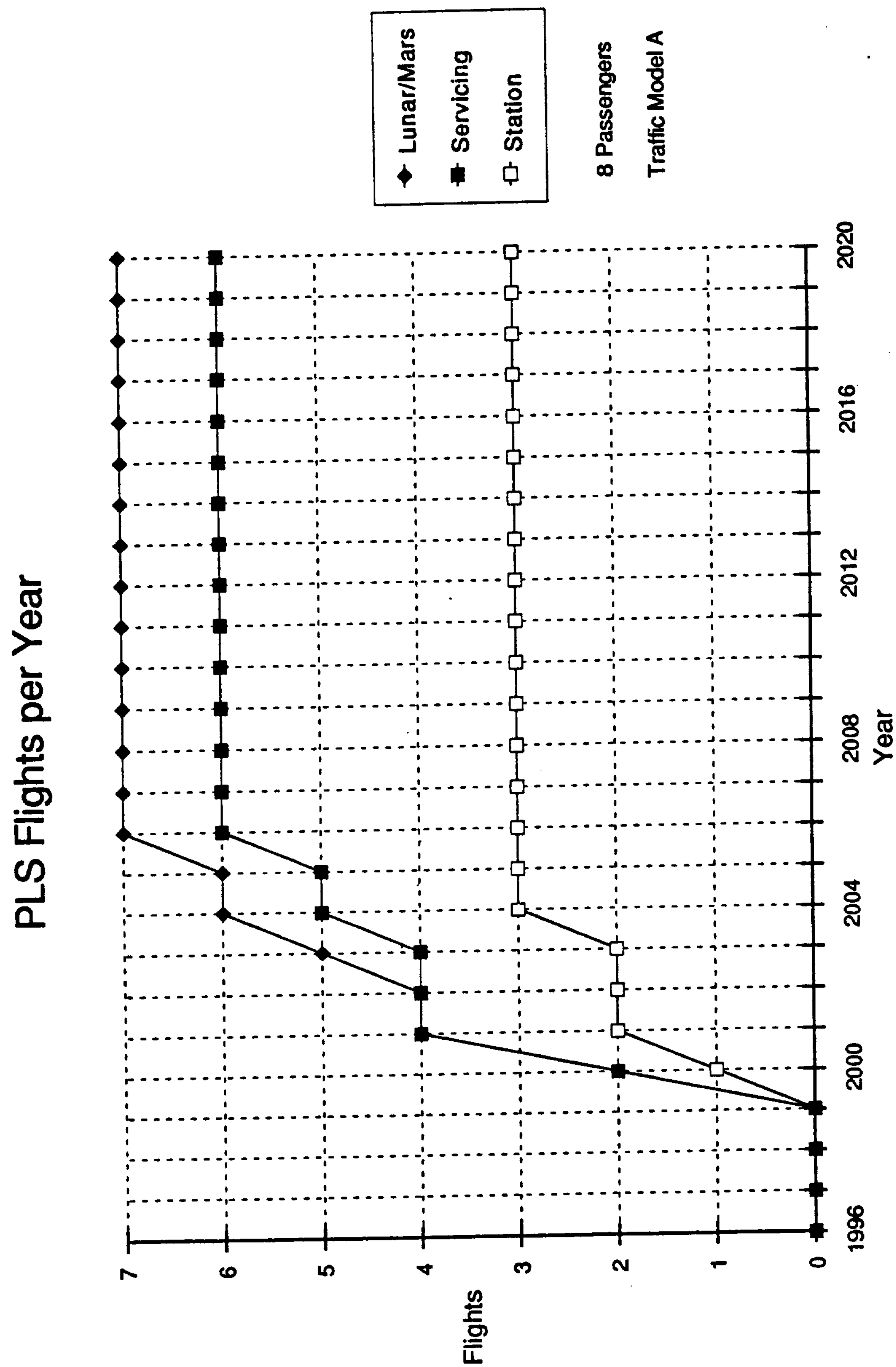
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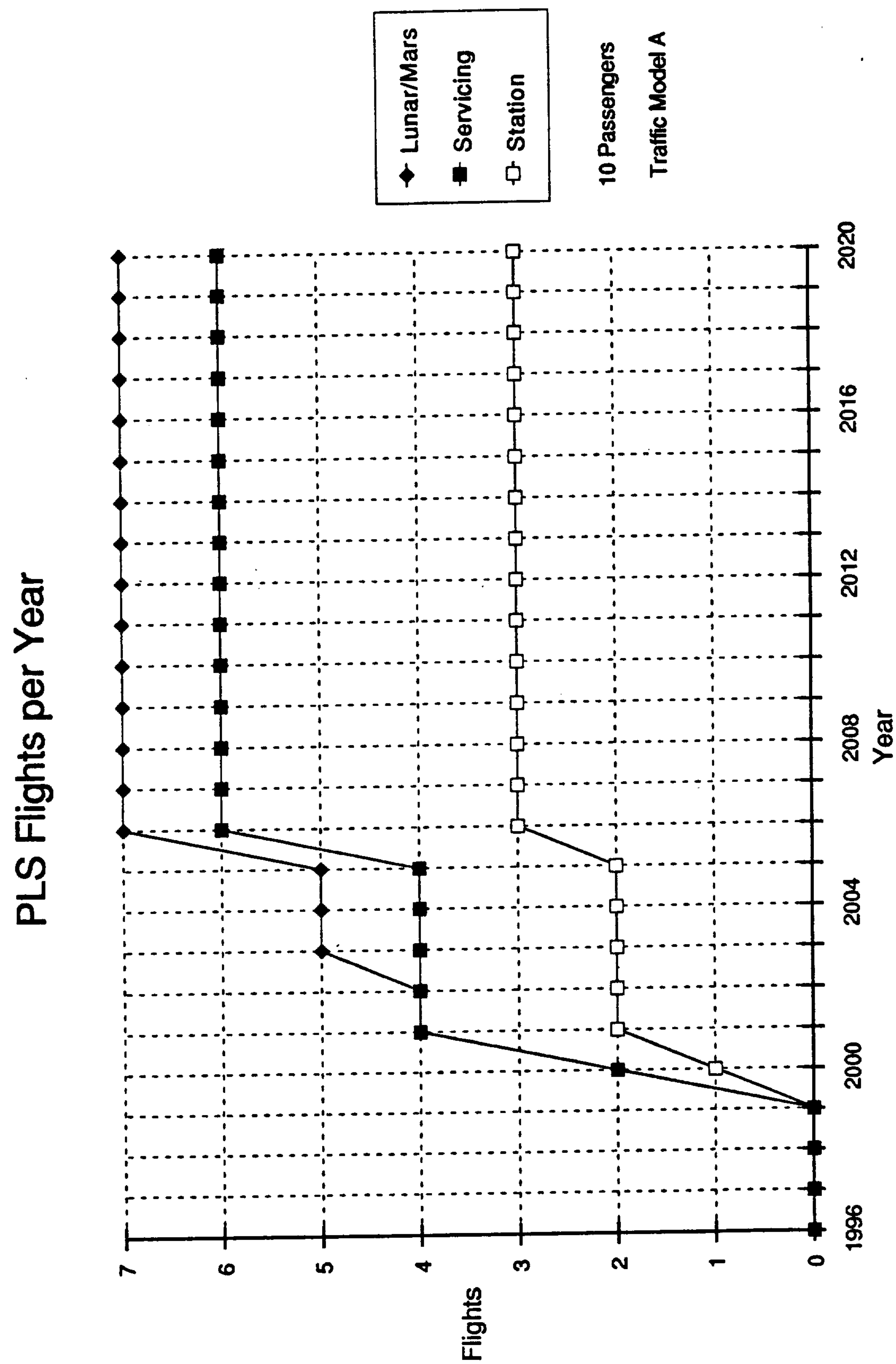
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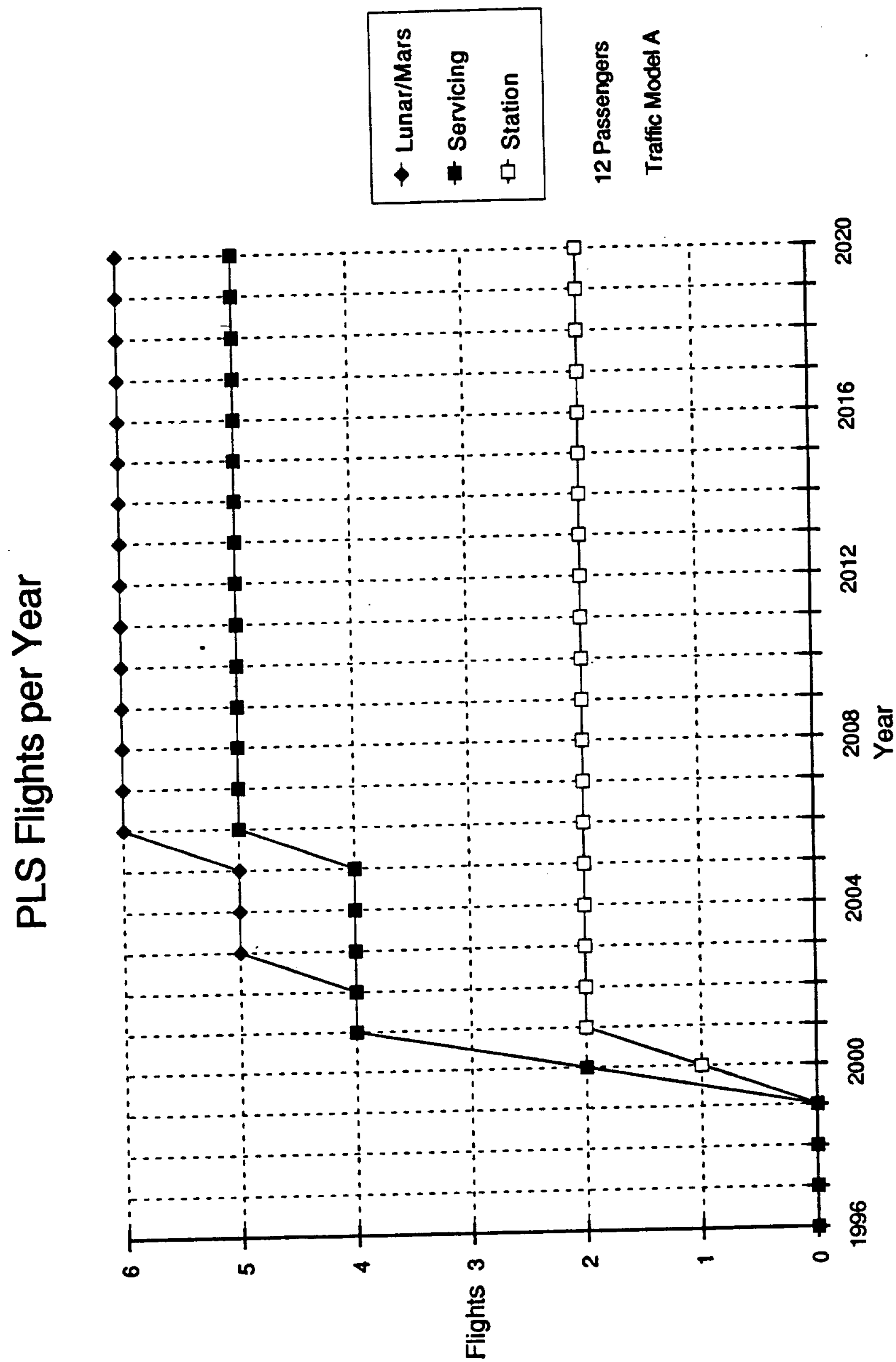
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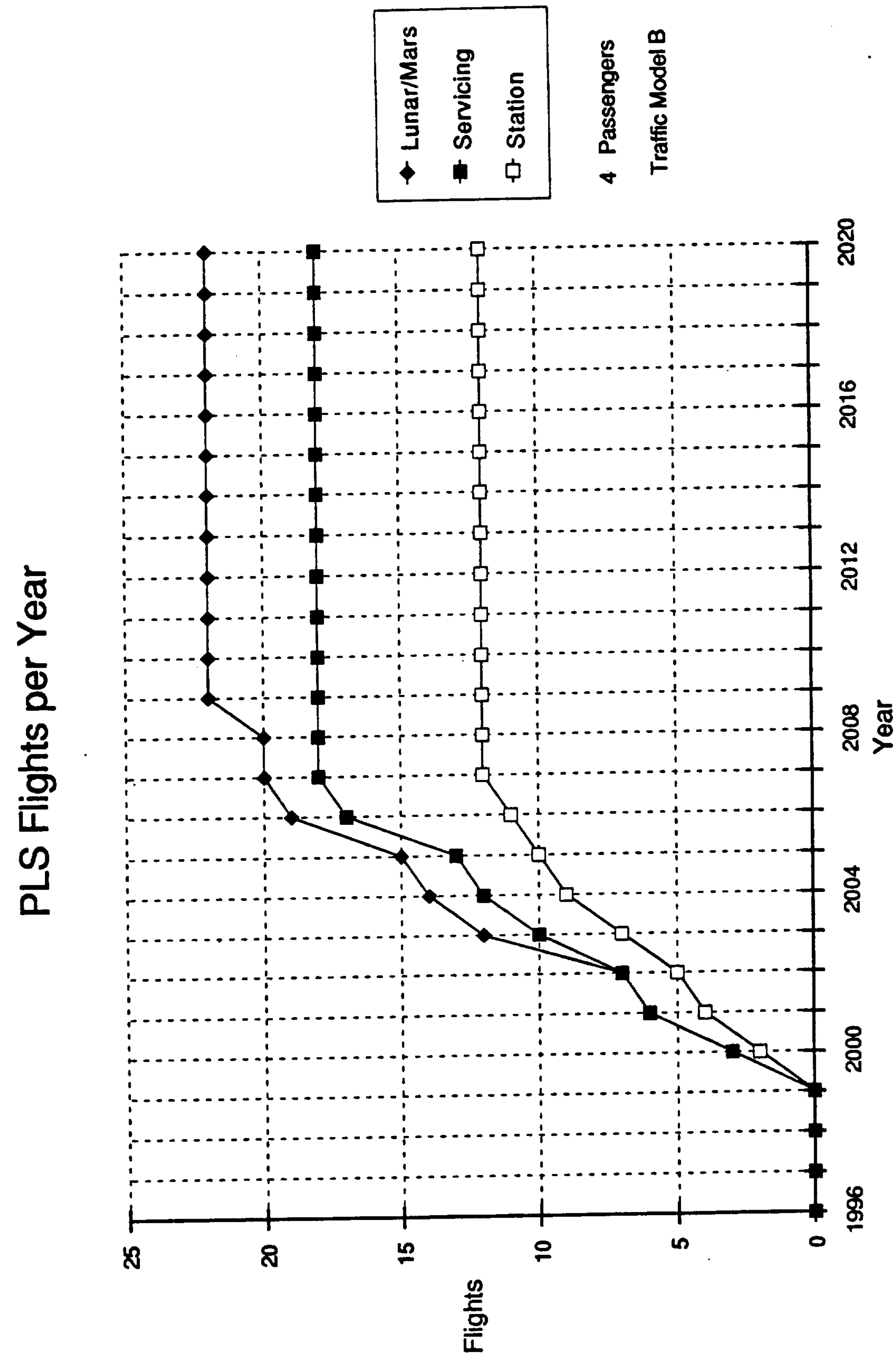
2016
2020


PLS Flights per Year
Lunar/Mars
Servicing
Station
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Flights
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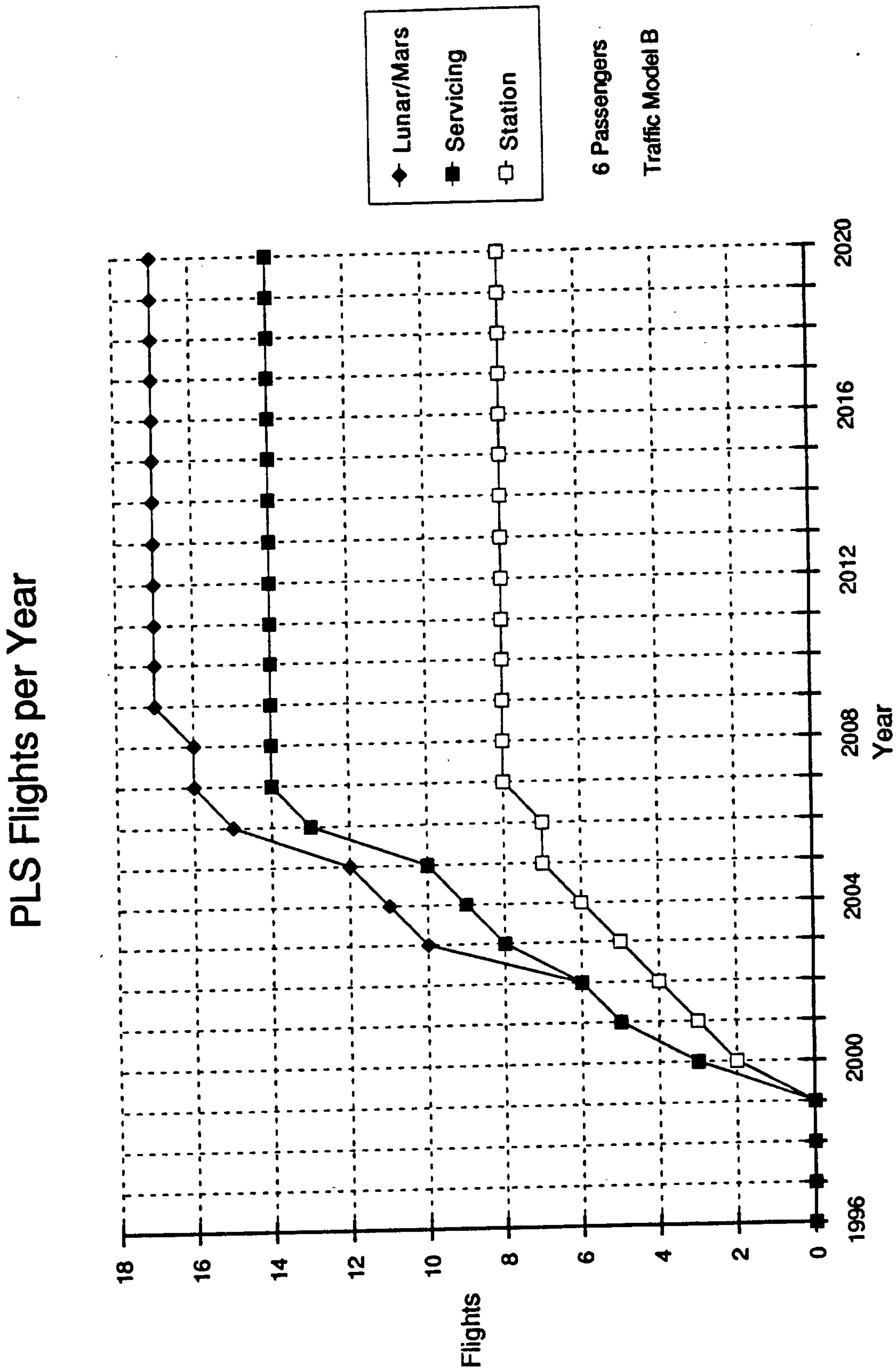
2016
2020
Year


PLS Flights per Year
Lunar/Mars
Servicing
Station
6 Passengers
Traffic Model B
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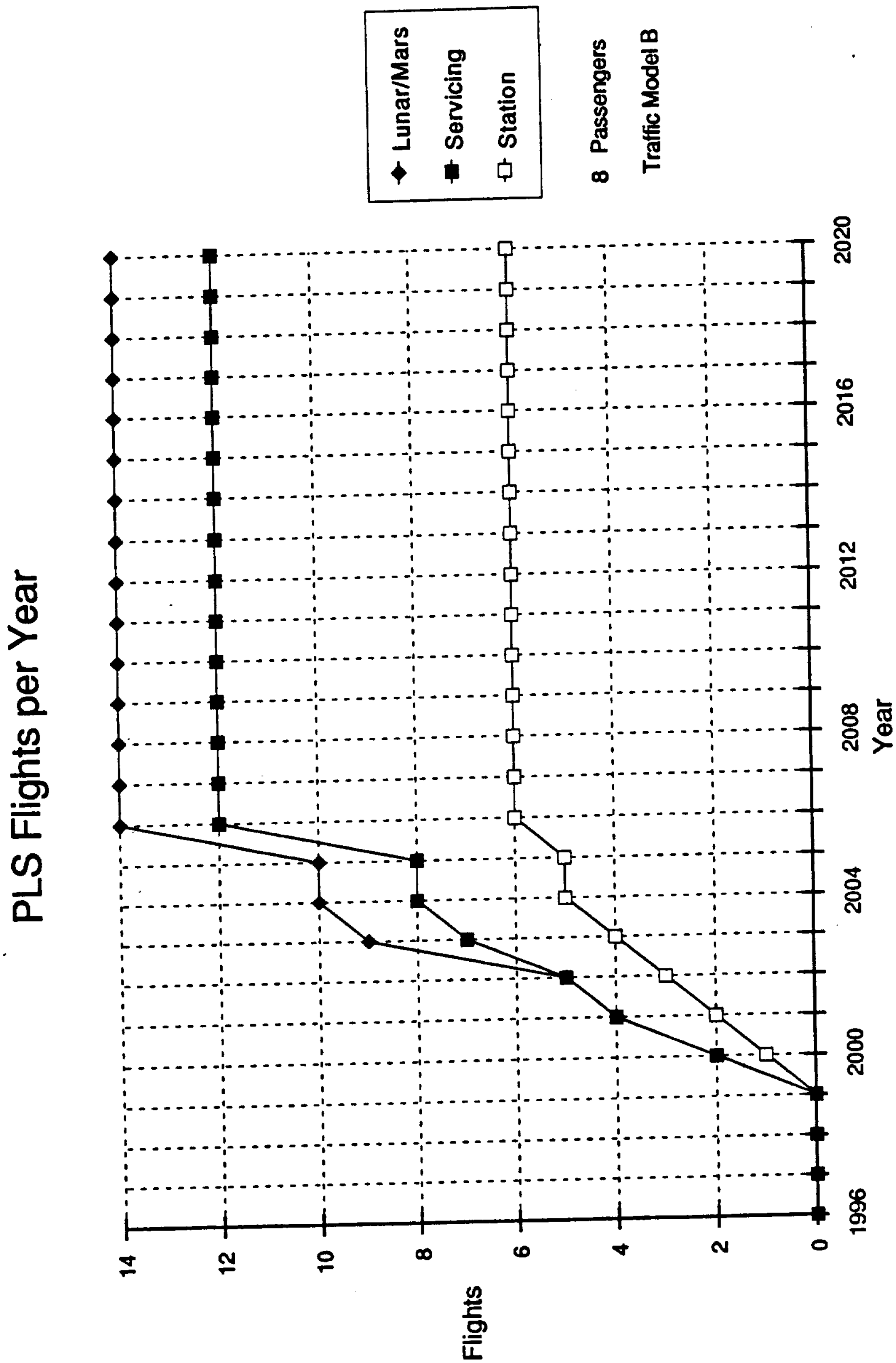
PLS Flights per Year
Lunar/Mars
Servicing
Station
8 Passengers
Traffic Model B
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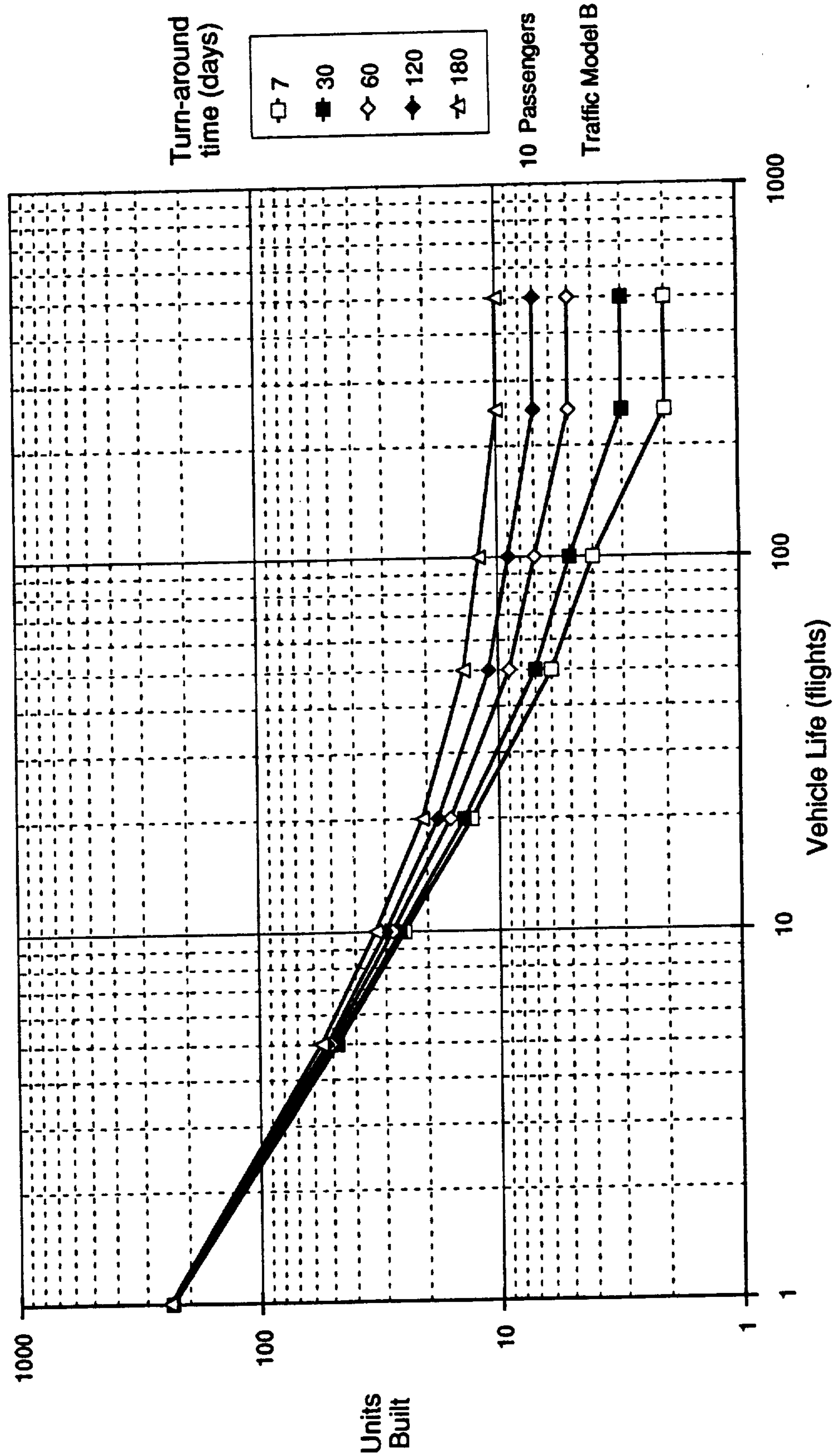
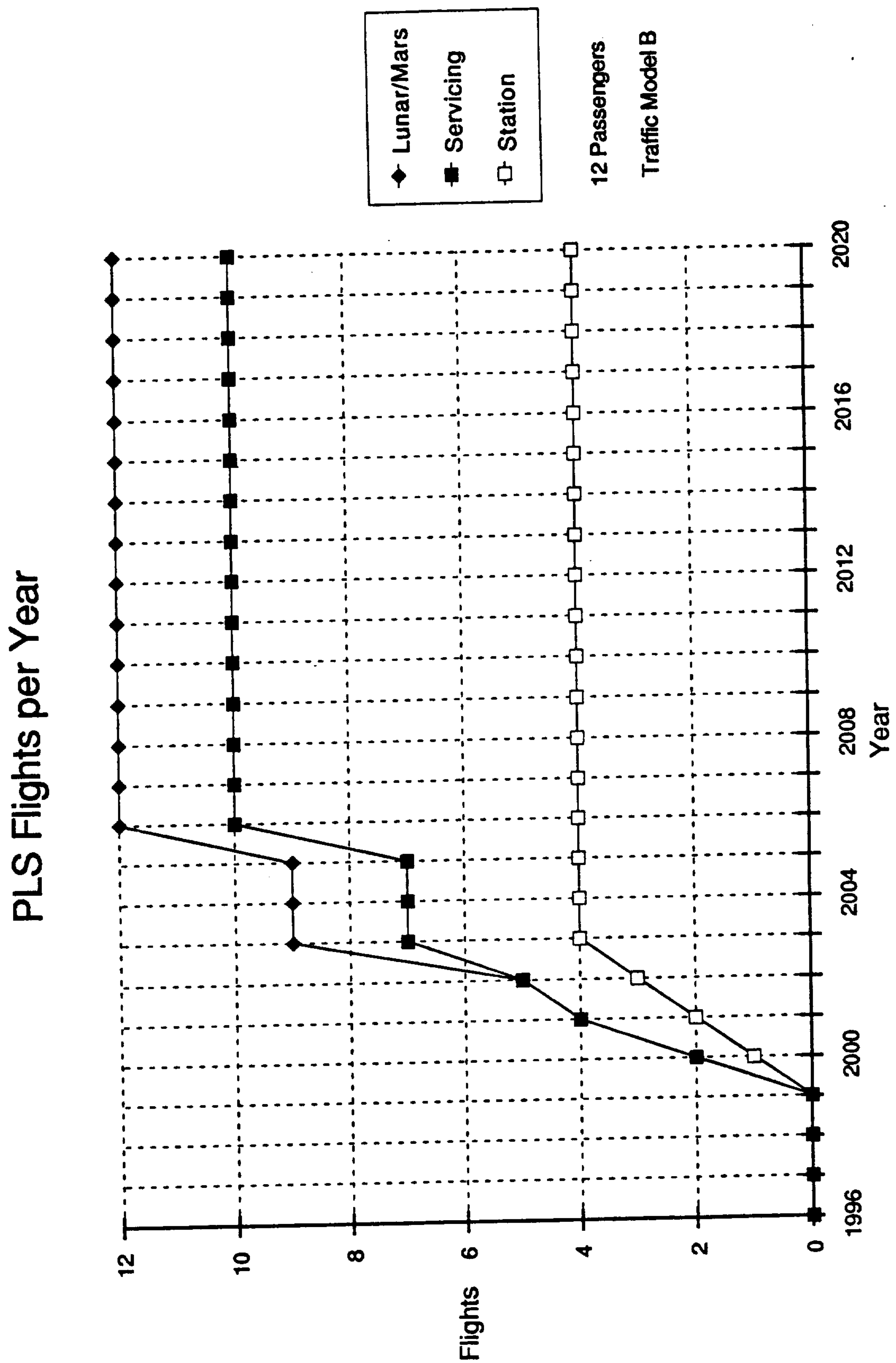
2016
2020
Year

PLS's Built vs. Life




PLS Flights per Year
Lunar/Mars
Servicing
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Traffic Model B
Flights
Year
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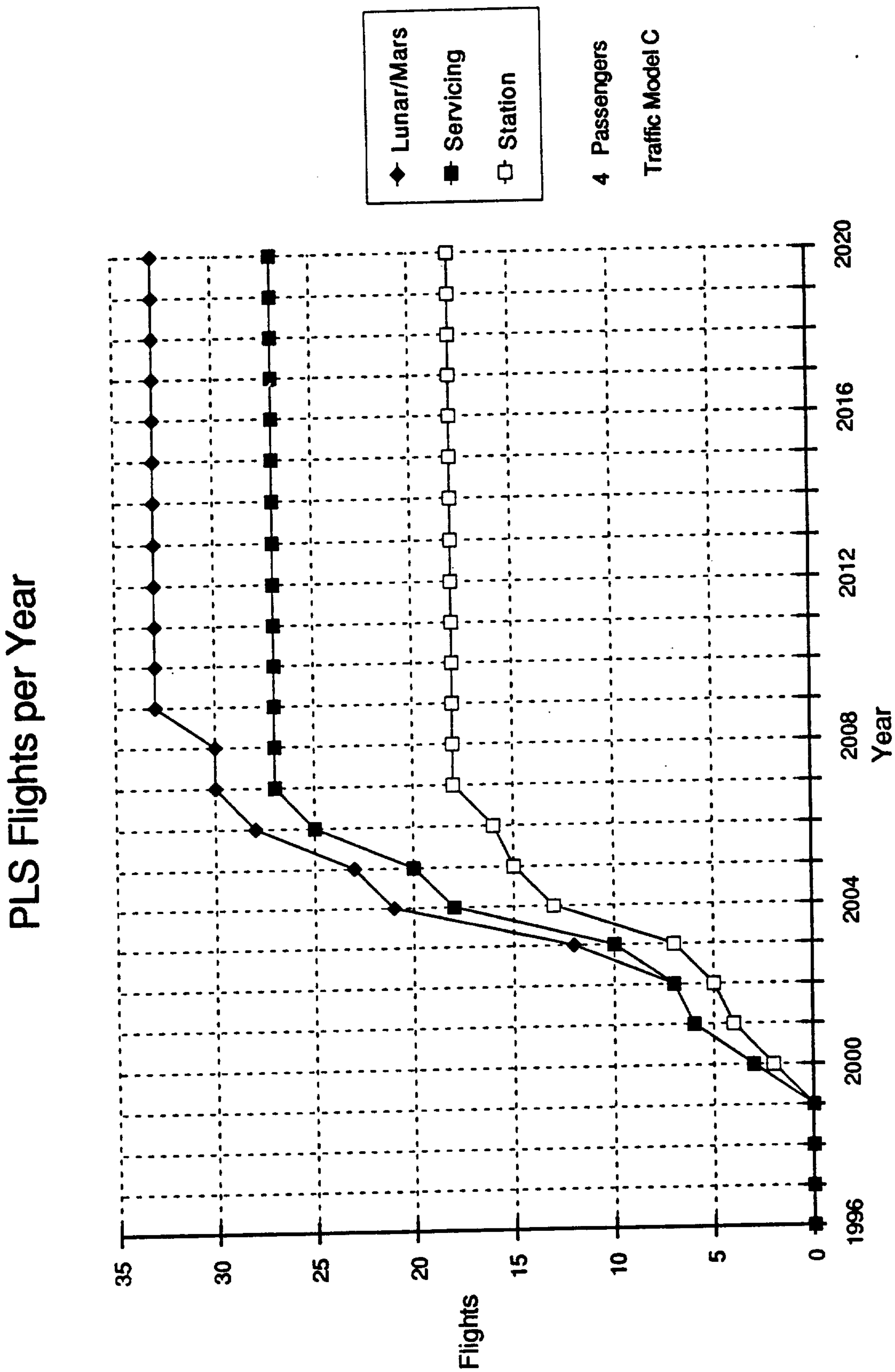
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Servicing
Station
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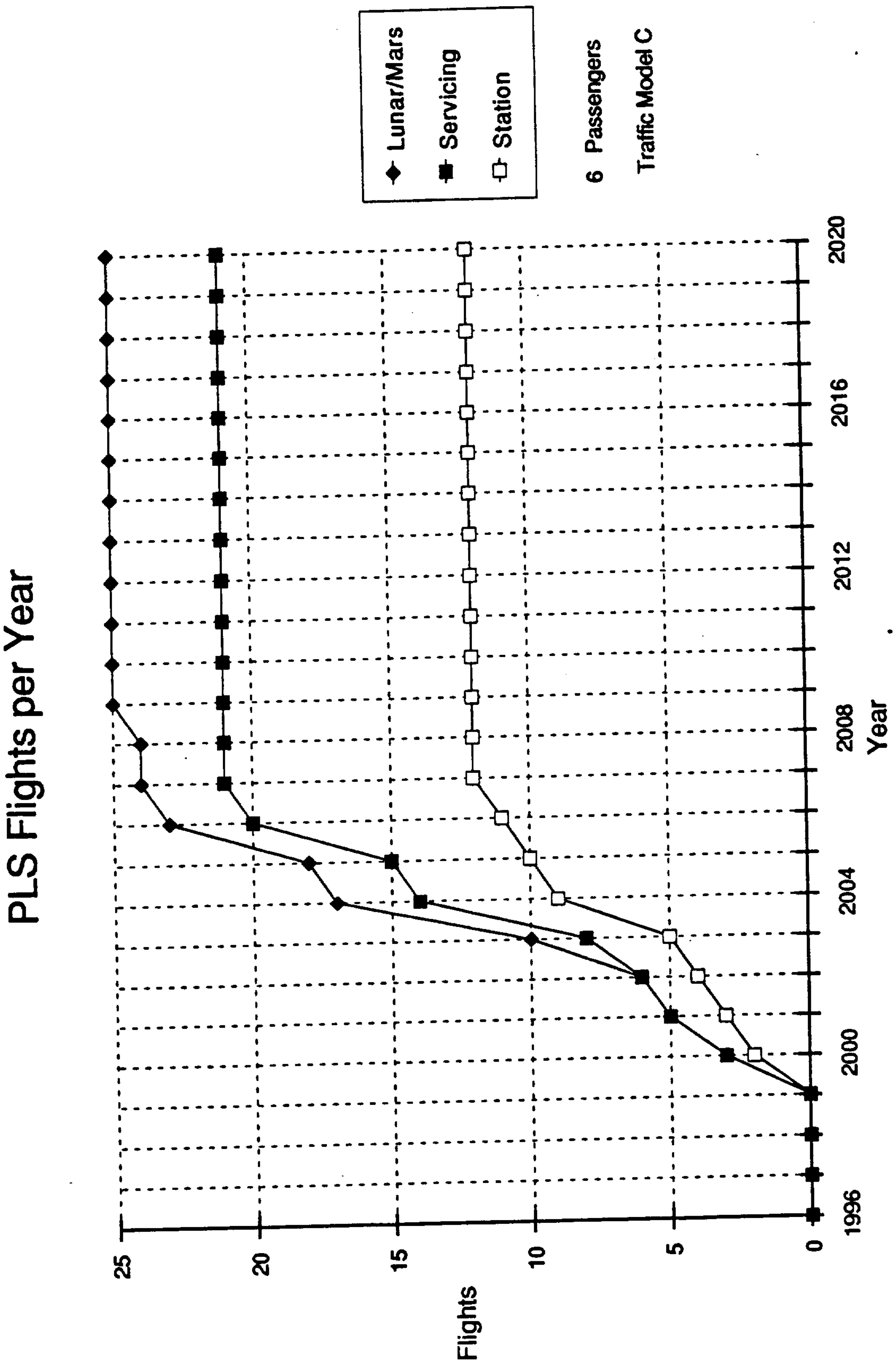
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Servicing
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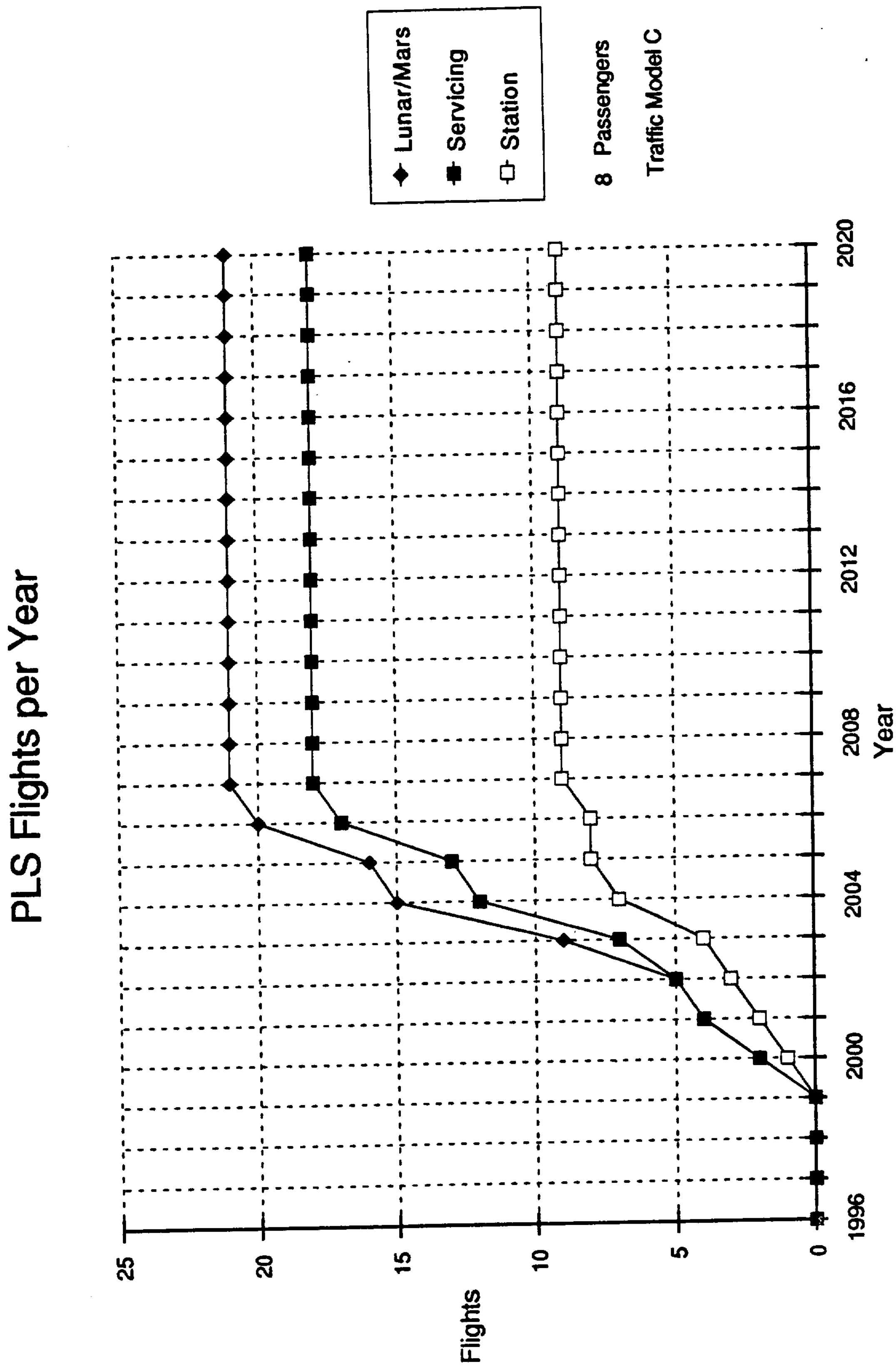
Year


PLS Flights per Year
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Servicing
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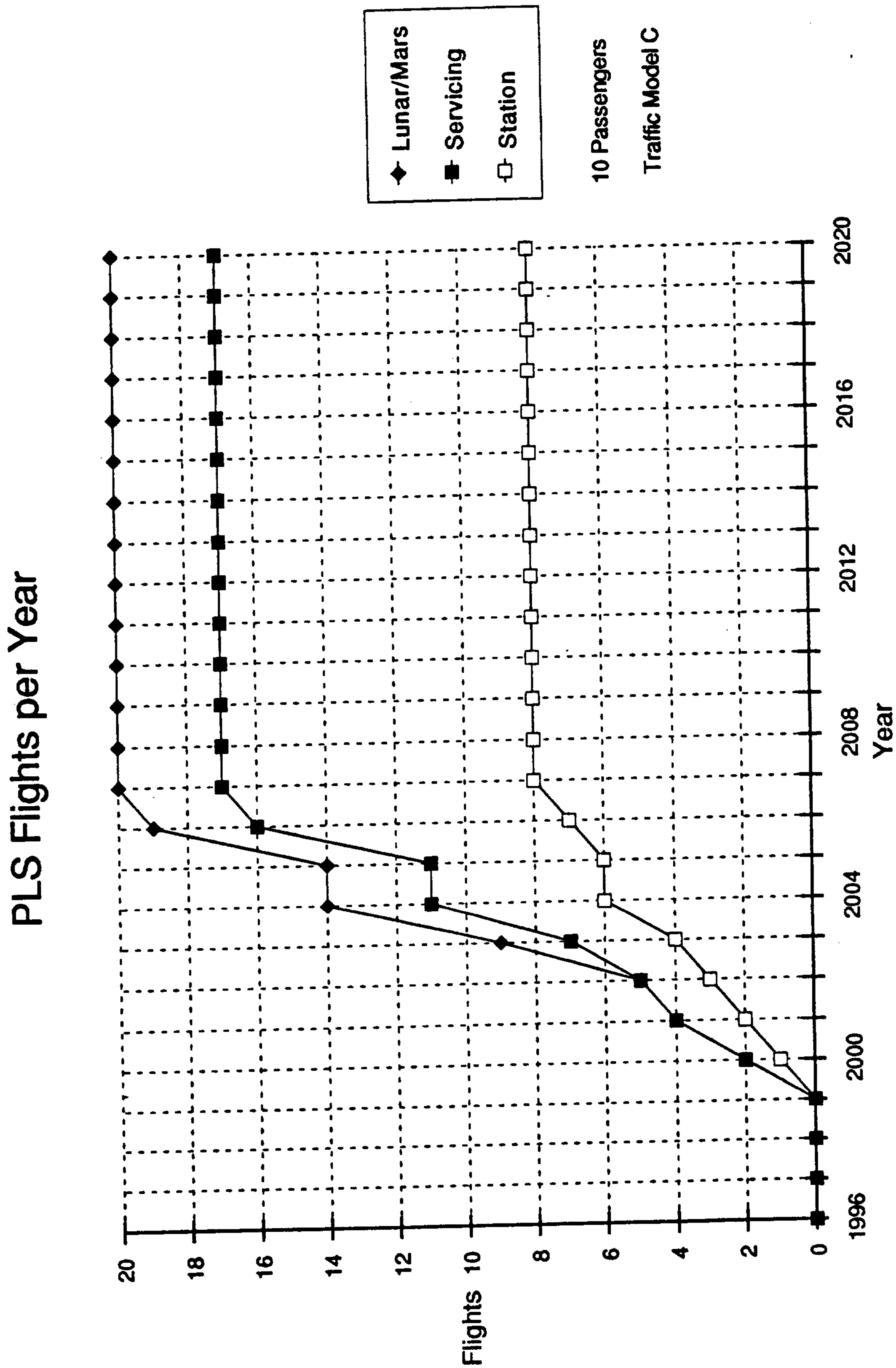
Year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Lunar/Mars
Servicing
Station
10 Passengers
Traffic Model C
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Year
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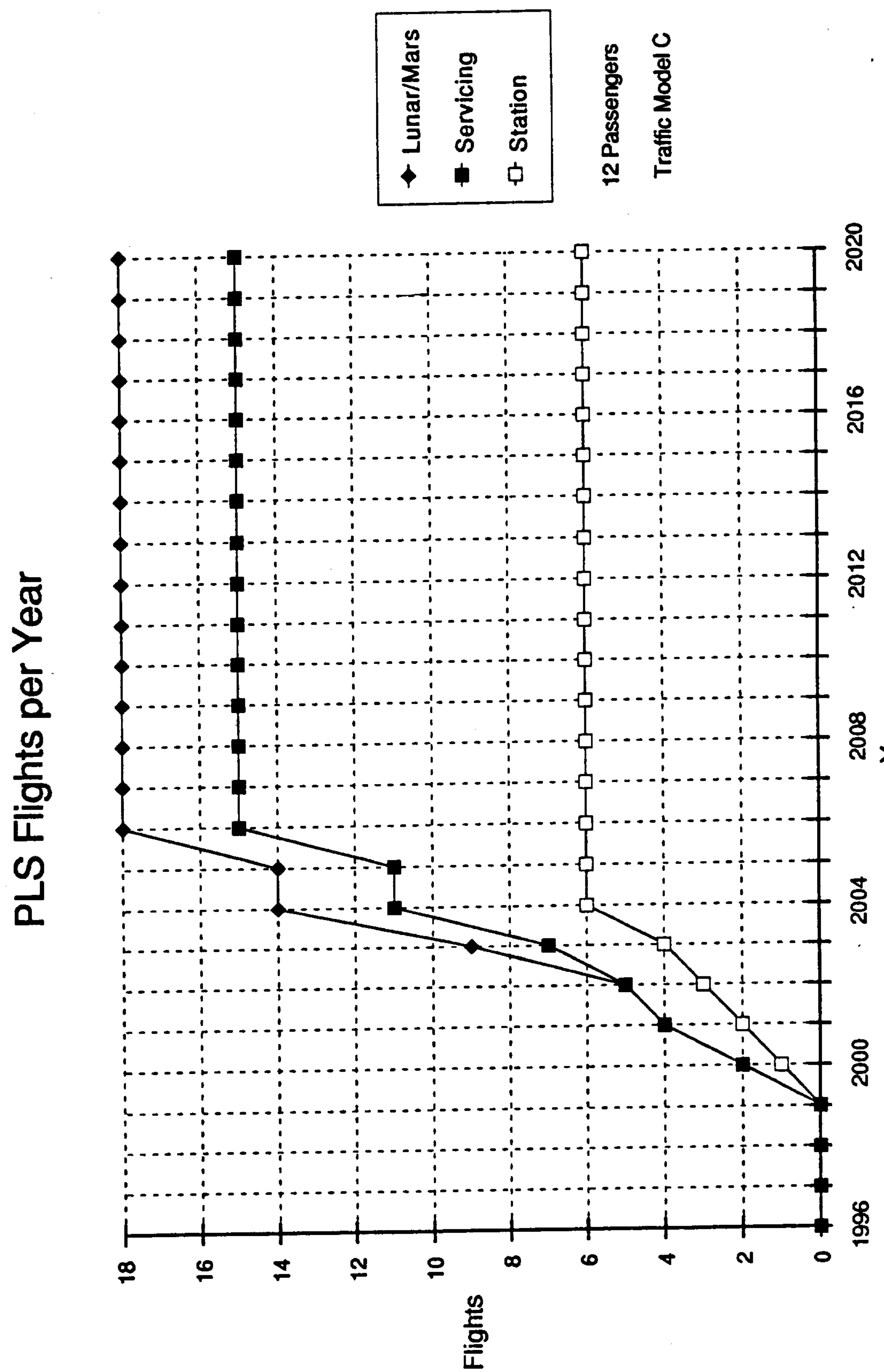
PLS Flights per Year
Lunar/Mars
Servicing
Station
12 Passengers
Traffic Model C
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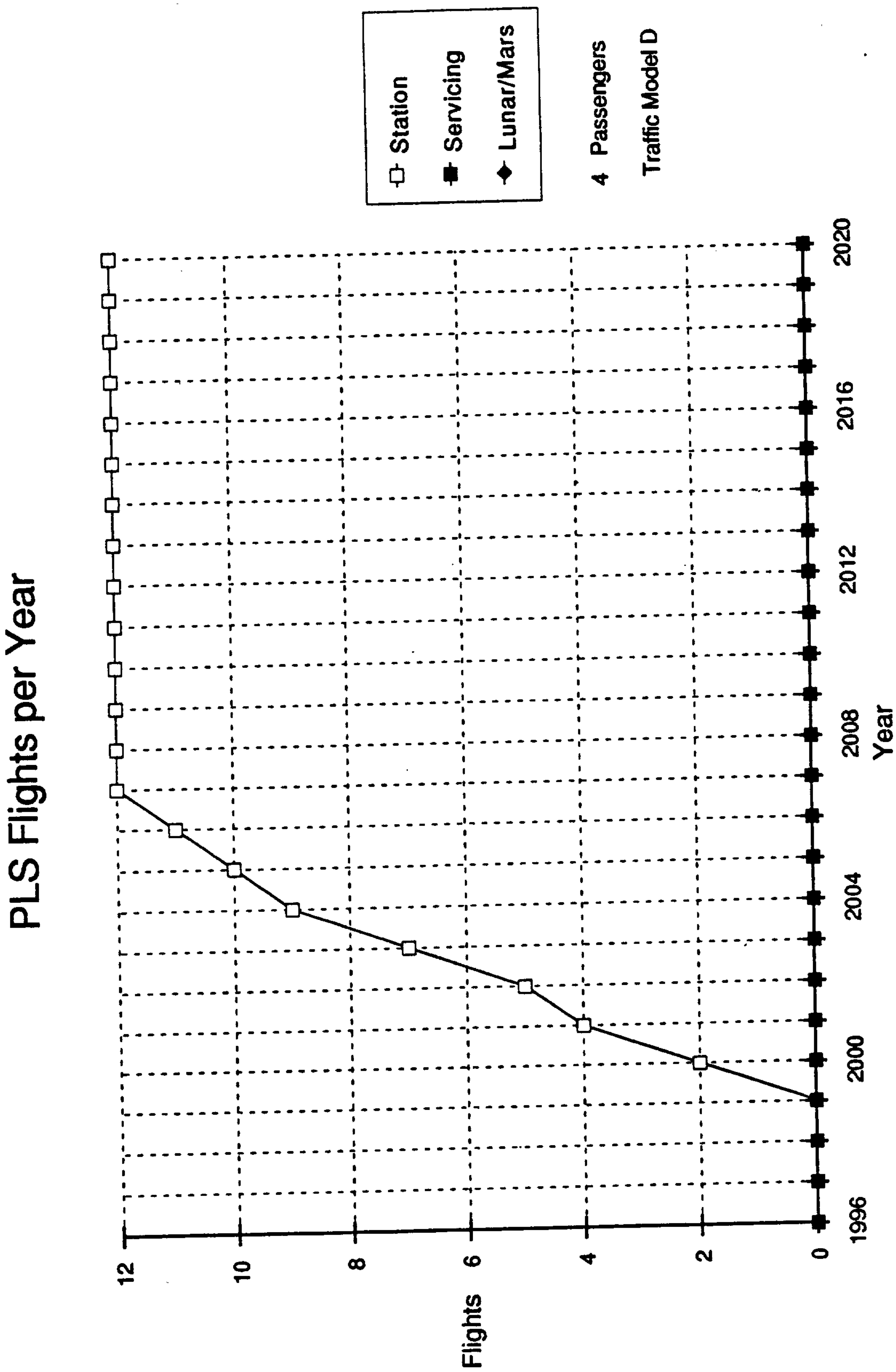
PLS Flights per Year
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Servicing
Lunar/Mars
4 Passengers
Traffic Model D
Flights
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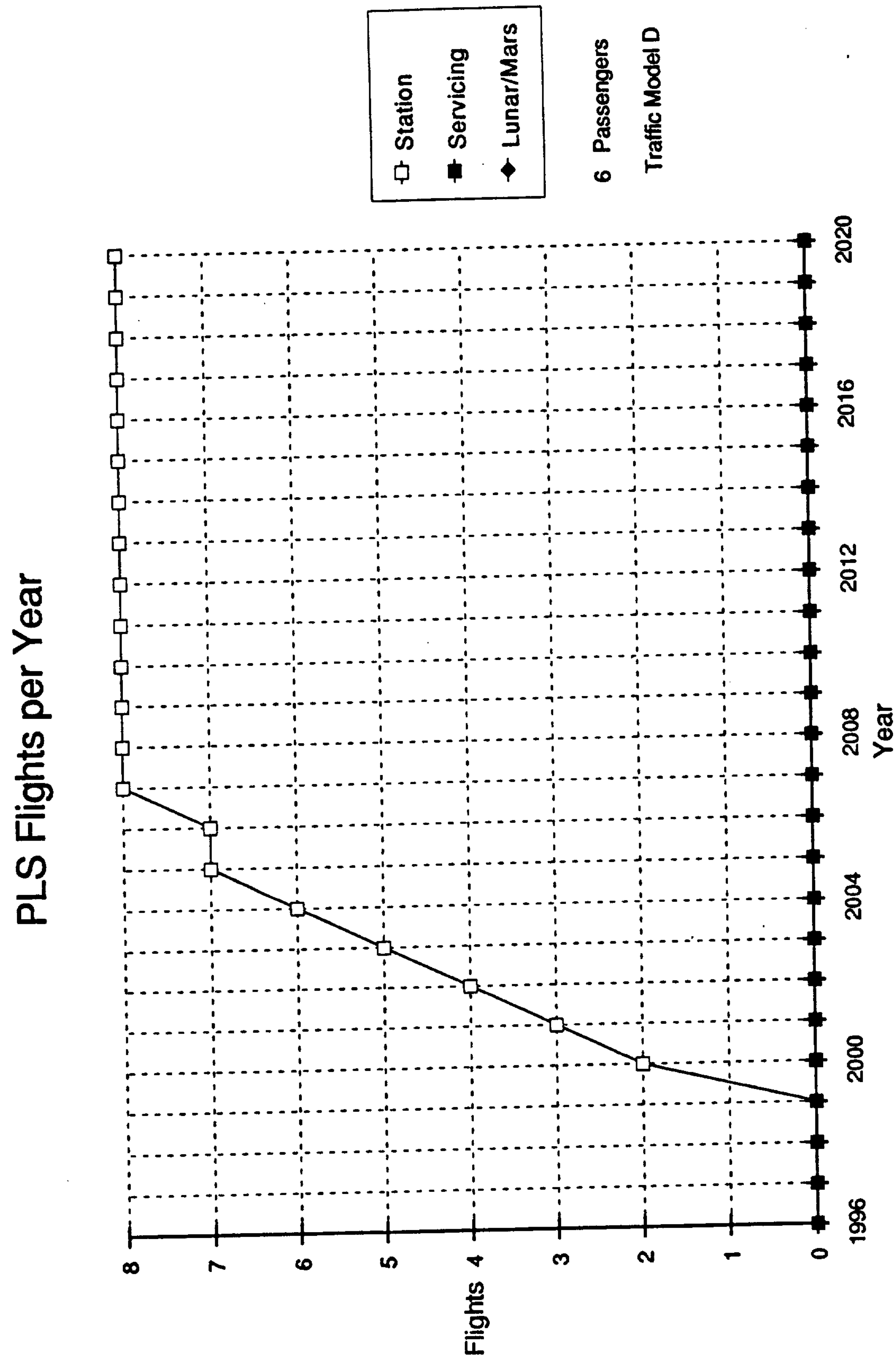
2020
Year


PLS Flights per Year
Station
Servicing
Lunar/Mars
6 Passengers
Traffic Model D
Flights
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Year
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2016
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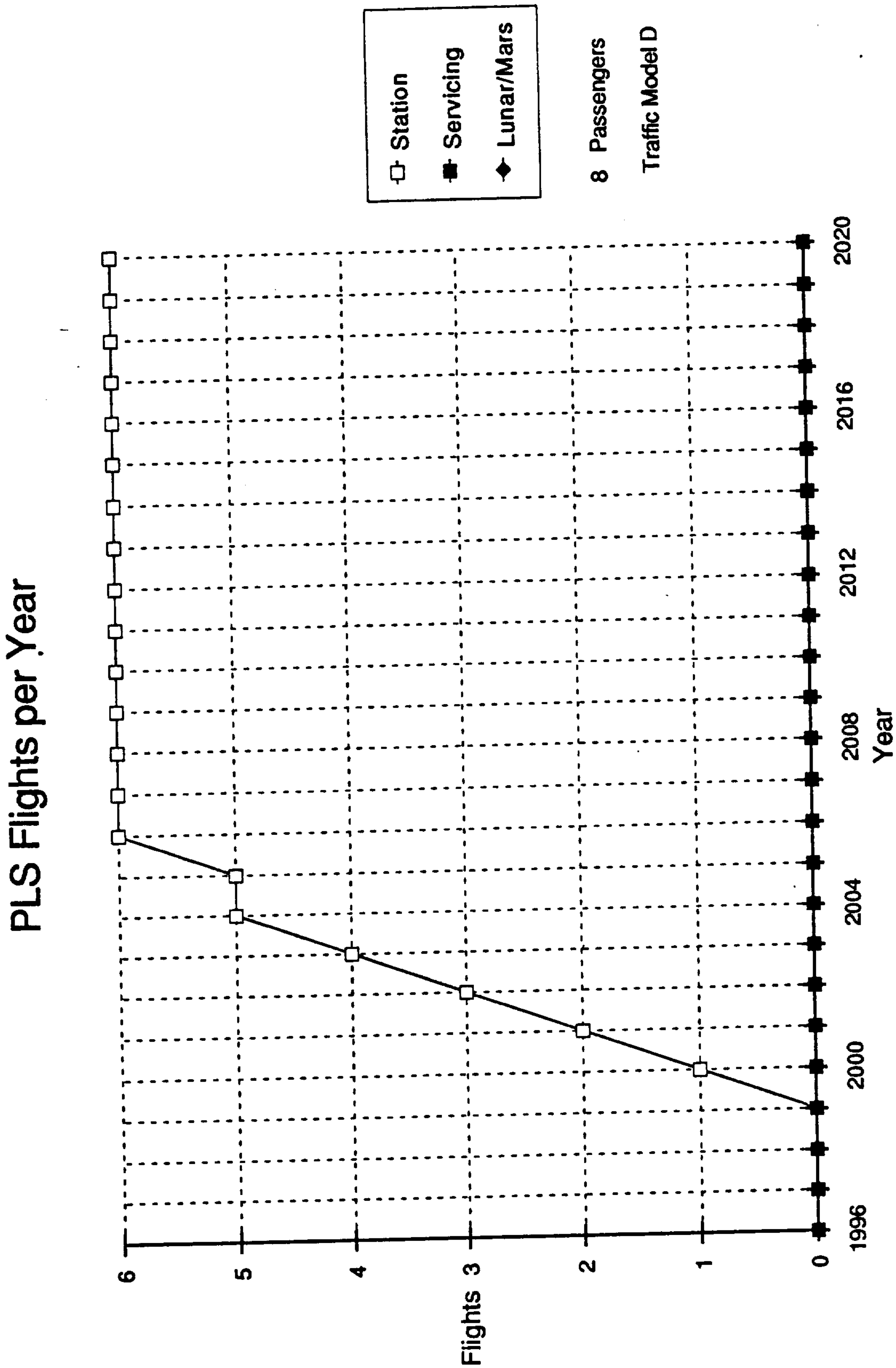
PLS Flights per Year
Station
Servicing
Lunar/Mars
8 Passengers
Traffic Model D
Flights
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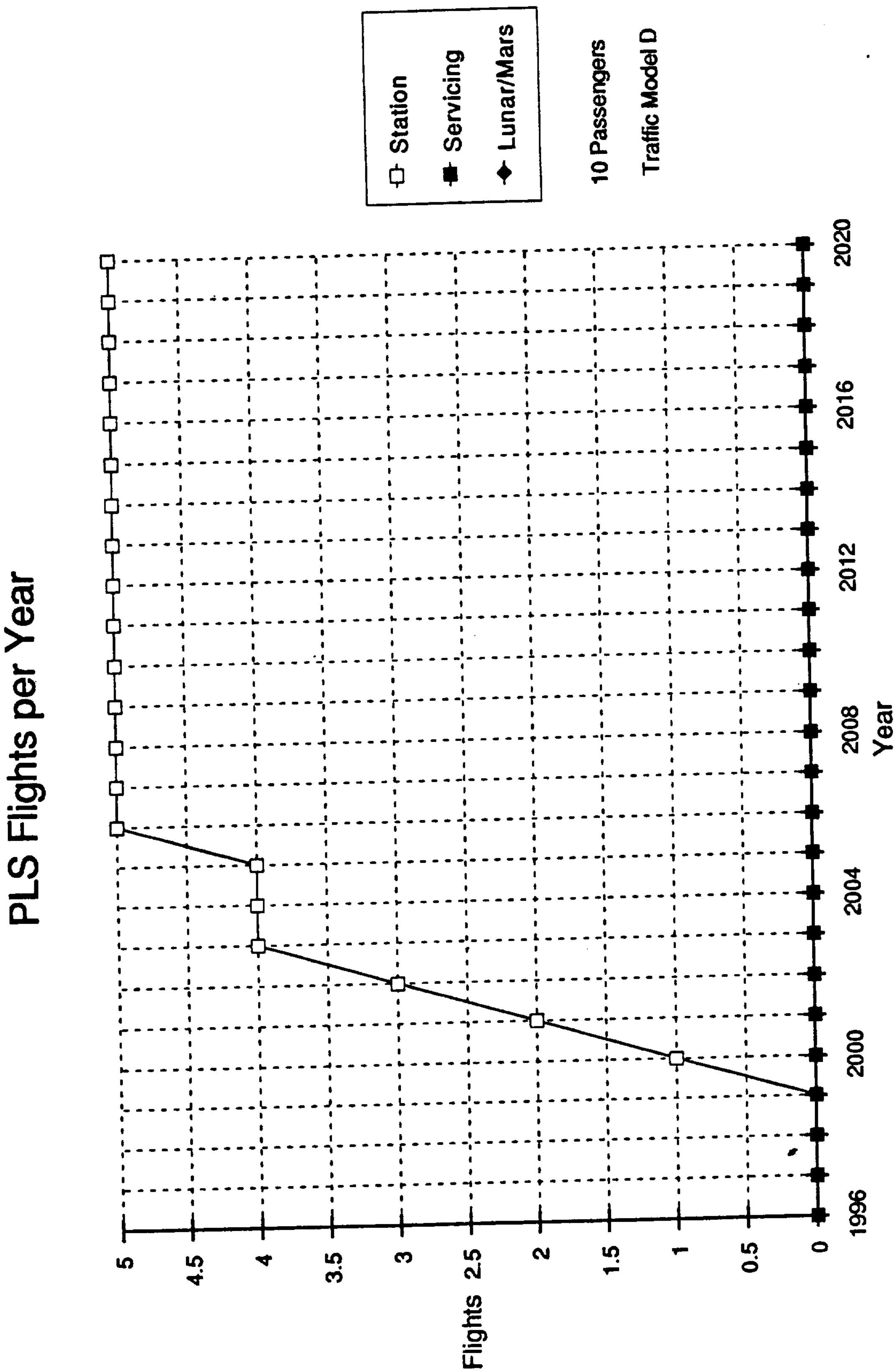
2020
Year


PLS Flights per Year
Station
Servicing
Lunar/Mars
10 Passengers
Traffic Model D
Flights
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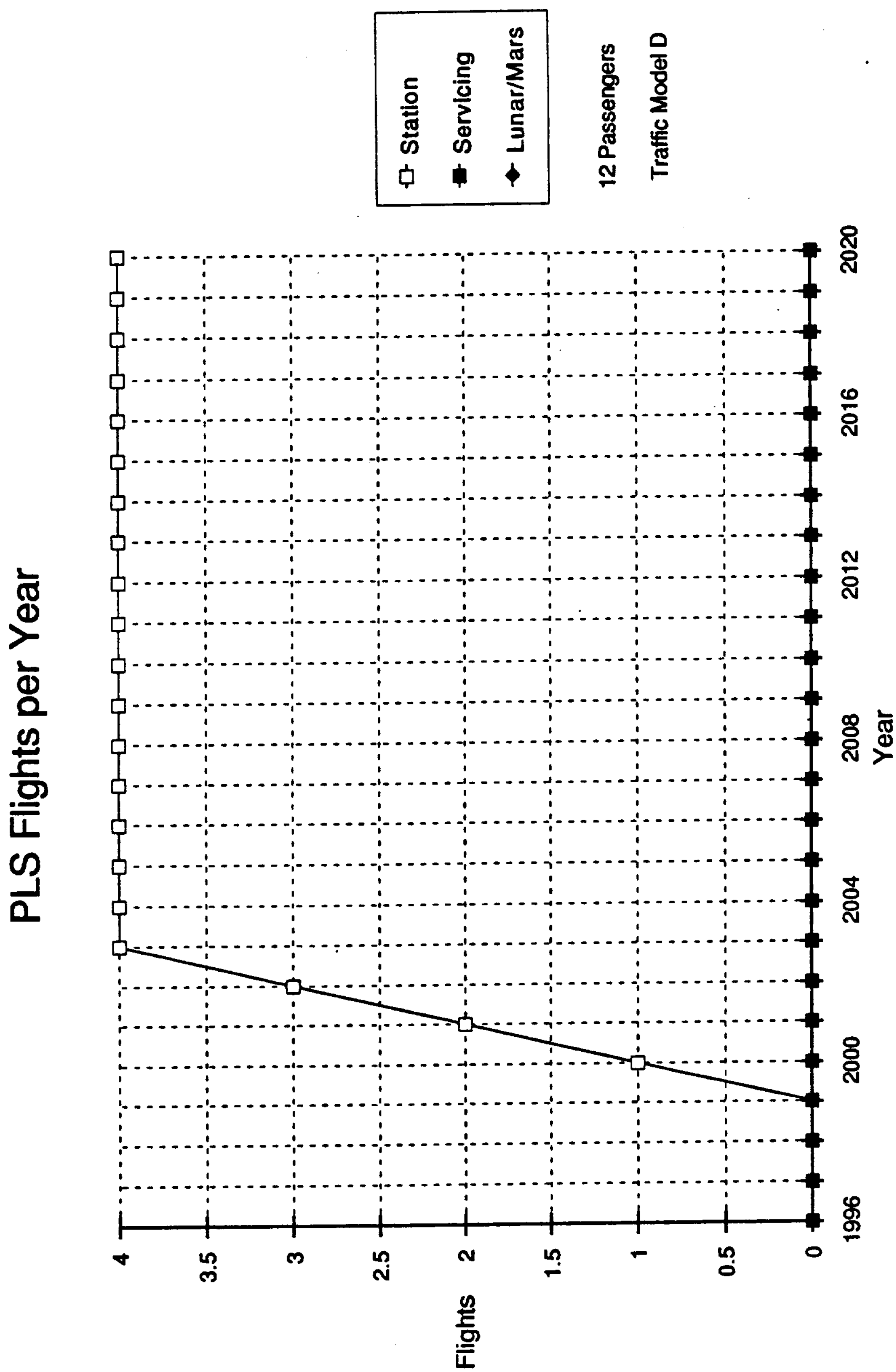
Year


PLS Flights per Year
Station
Servicing
Lunar/Mars
12 Passengers
Traffic Model D
Flights
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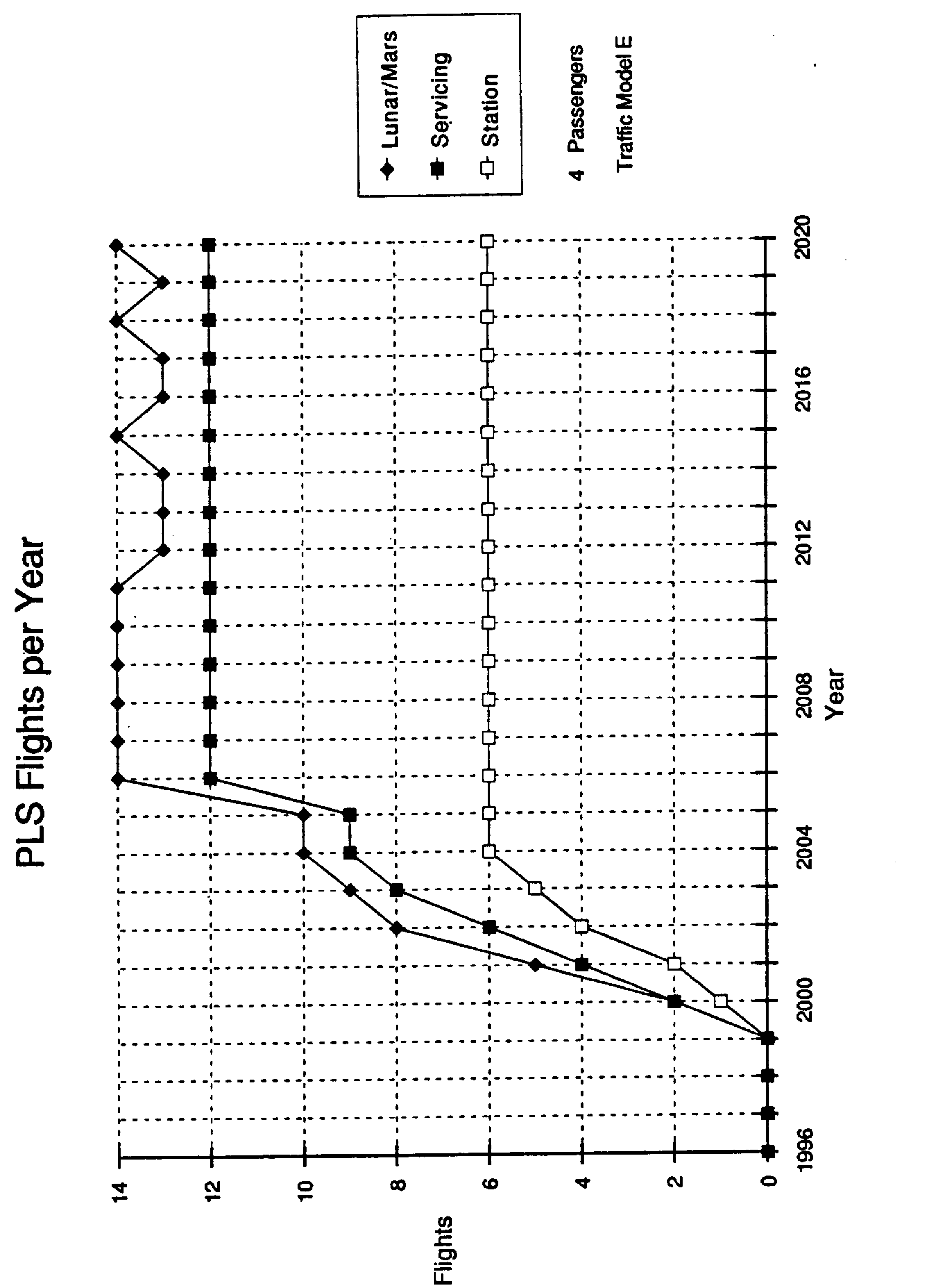
Year


PLS Flights per Year
Lunar/Mars
Servicing
Station
4 Passengers
Traffic Model E
Flights
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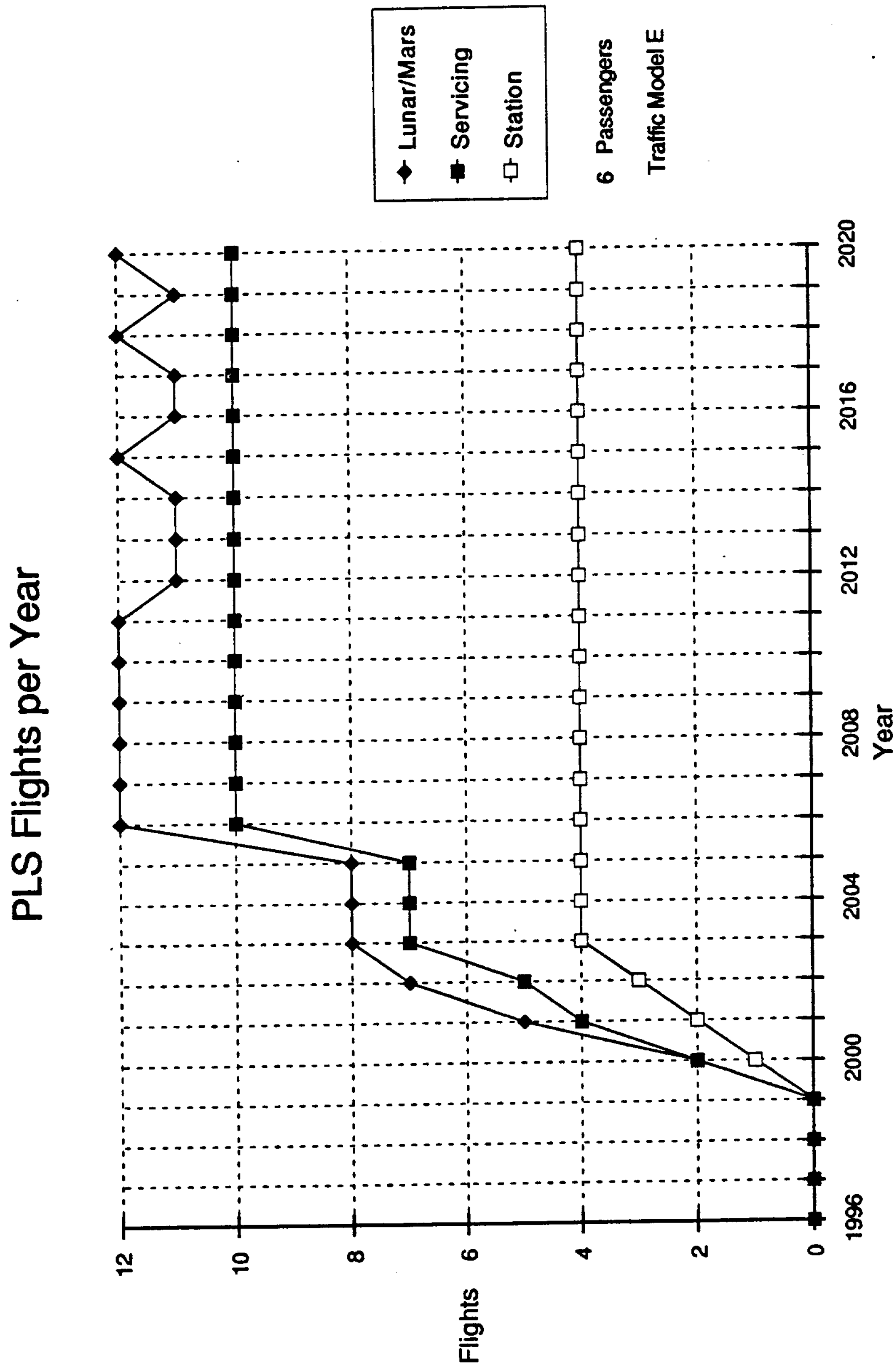
2016
2020



PLS Flights per Year
Lunar/Mars
Servicing
Station
6 Passengers
Traffic Model E
Flights
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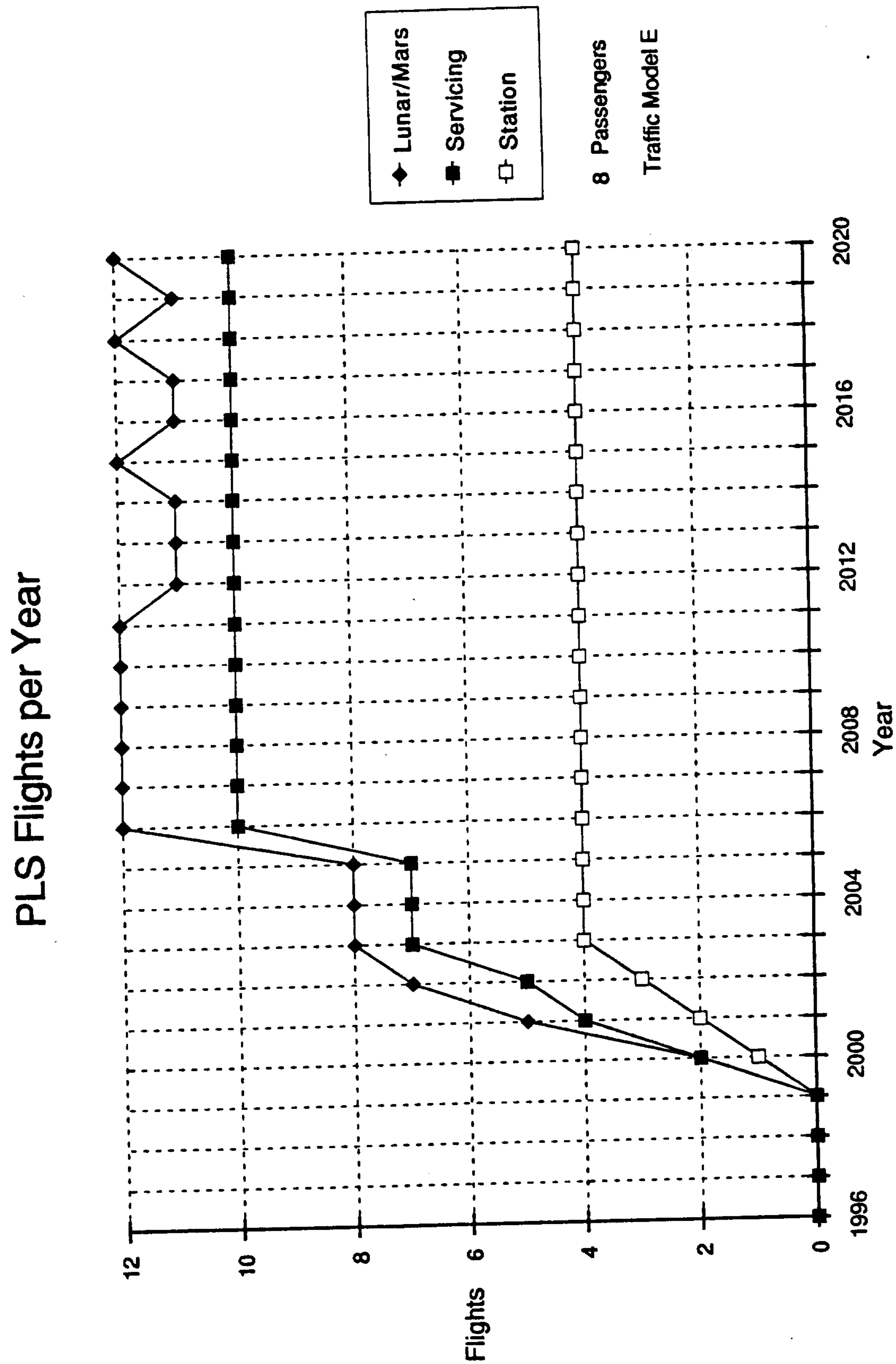
2020
Year


PLS Flights per Year
Lunar/Mars
Servicing
Station
8 Passengers
Traffic Model E
Flights
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1996
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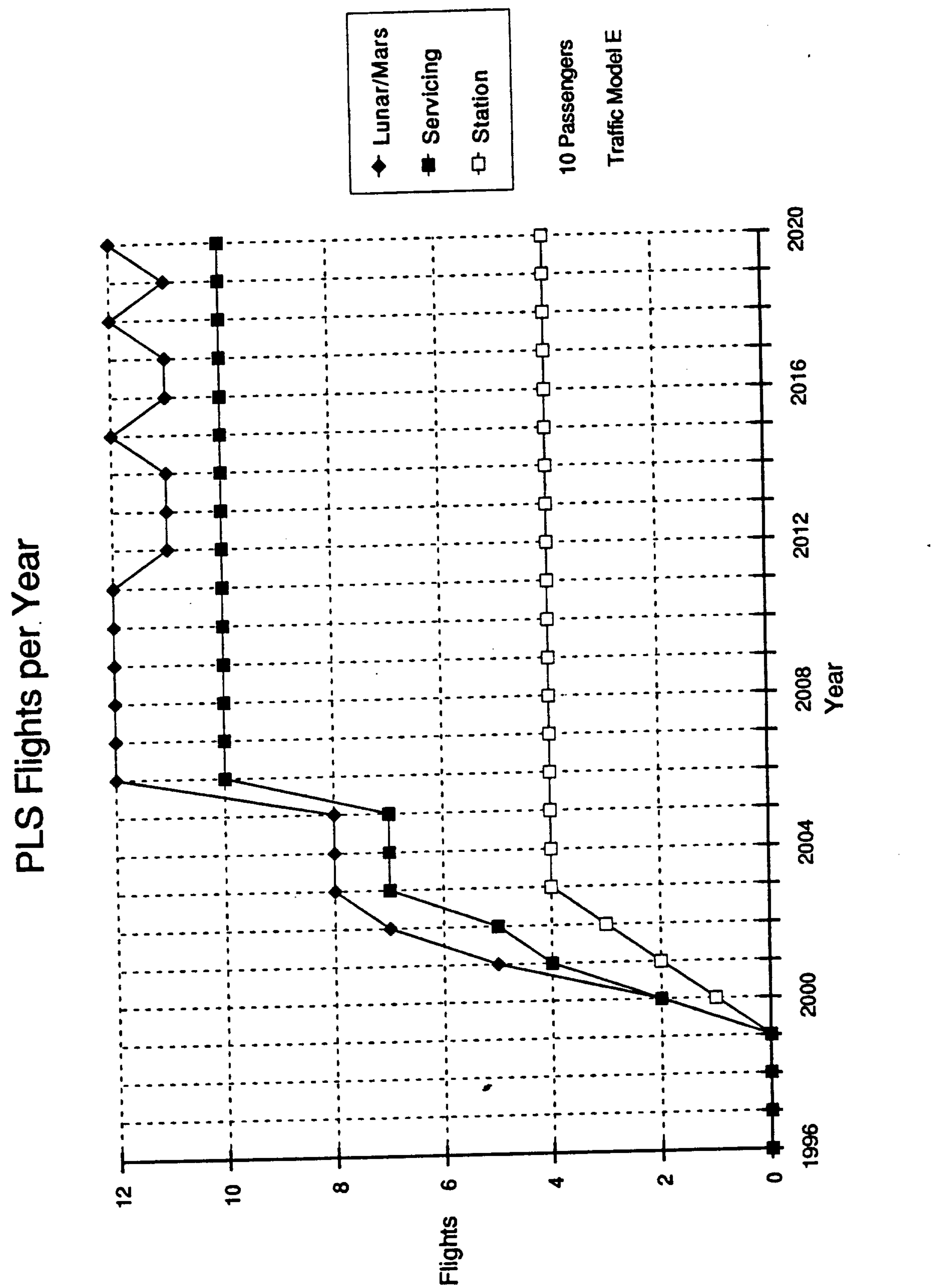
Year


PLS Flights per Year
Lunar/Mars
Servicing
Station
10 Passengers
Traffic Model E
Flights
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1996
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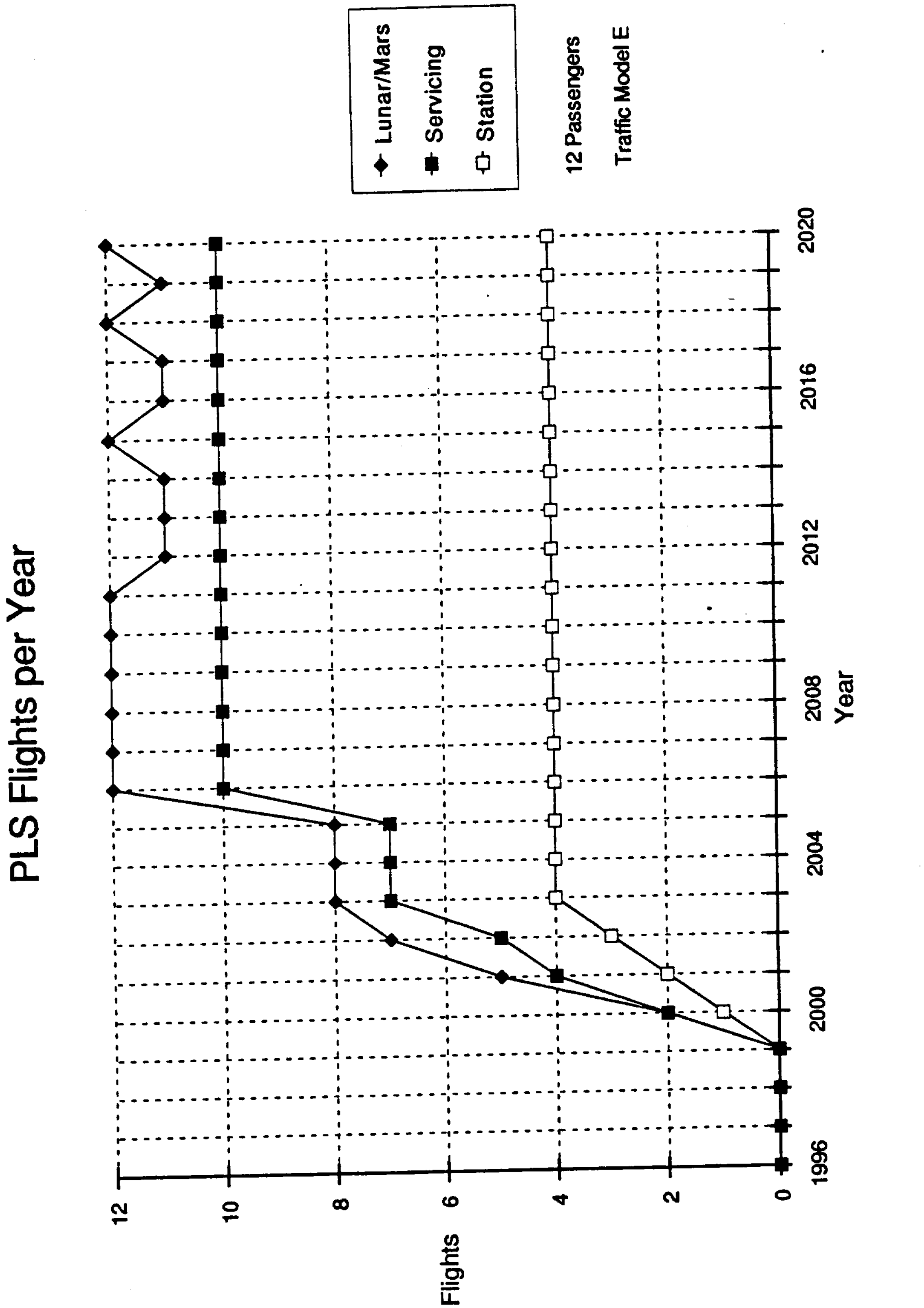
2020
Year


PLS Flights per Year
Lunar/Mars
Servicing
Station
12 Passengers
Traffic Model E
Flights
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1996
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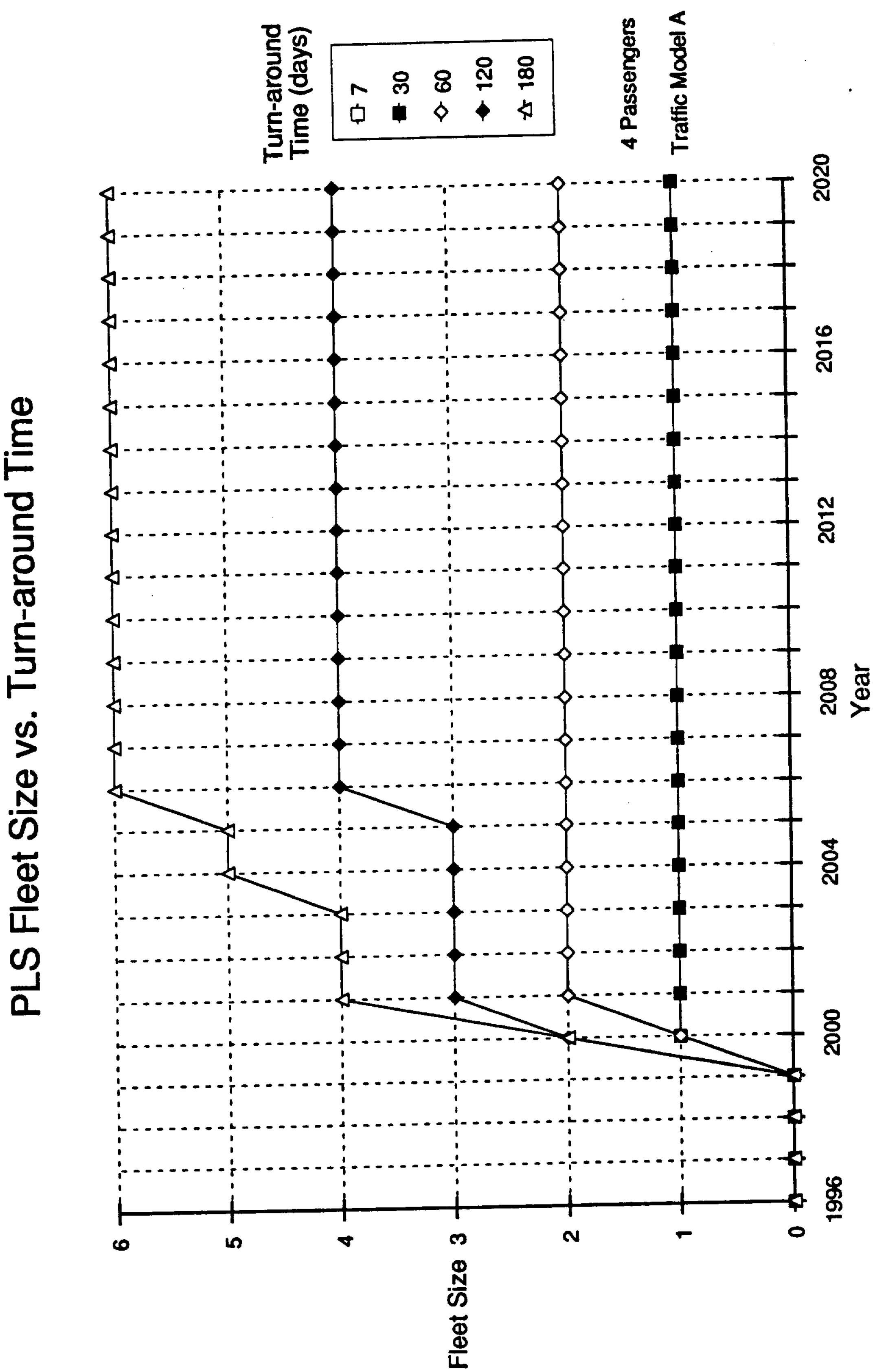
2020
Year


PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
7
30
60
120
180
4 Passengers
Traffic Model A
Fleet Size
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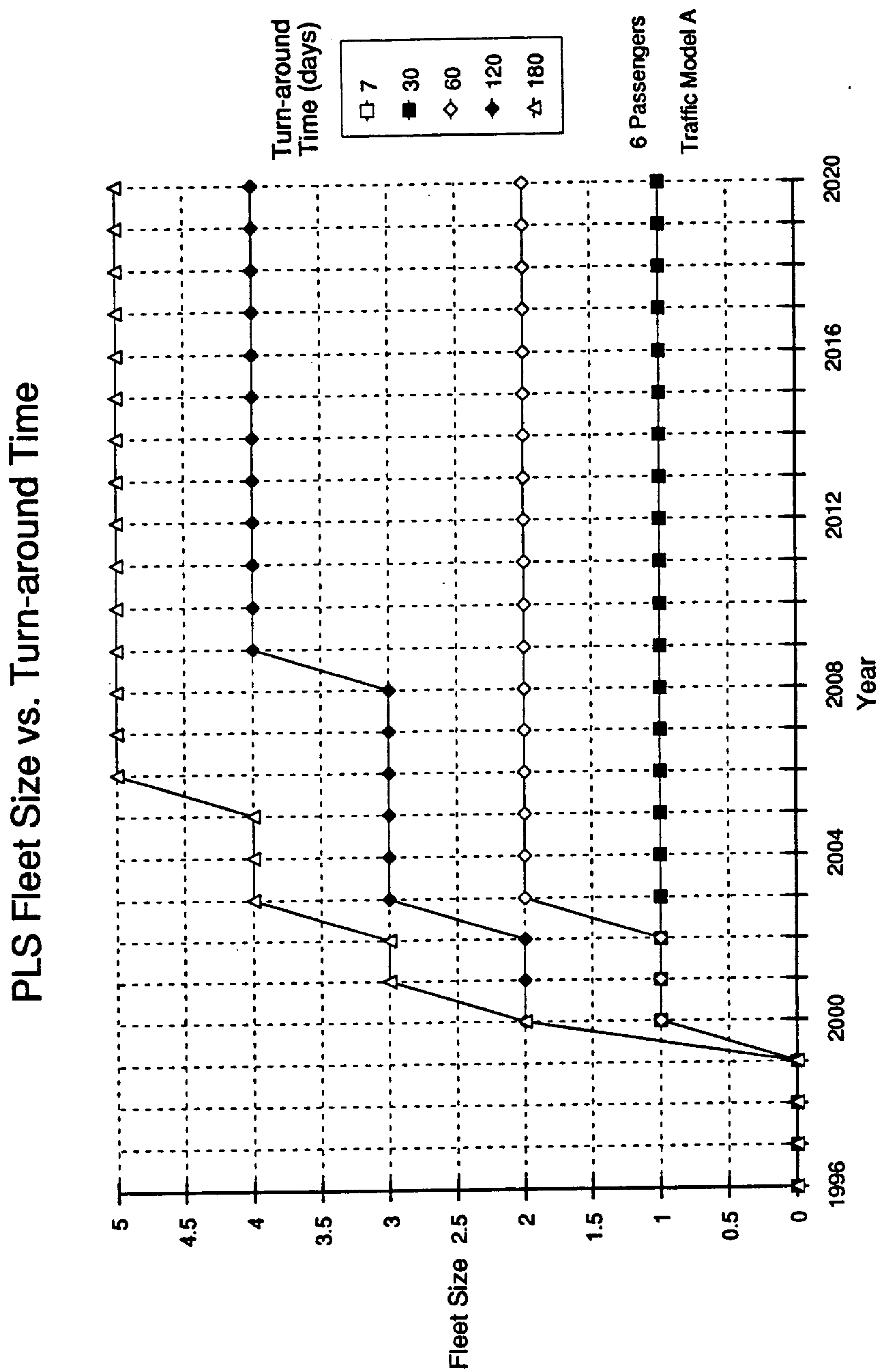
1
2
3
4
5
6
Year
1996
2000
2004
2008
2012
2016
2020


PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
7
30
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120
180
6 Passengers
Traffic Model A
Fleet Size
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0.5
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5
Year
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2012
2016
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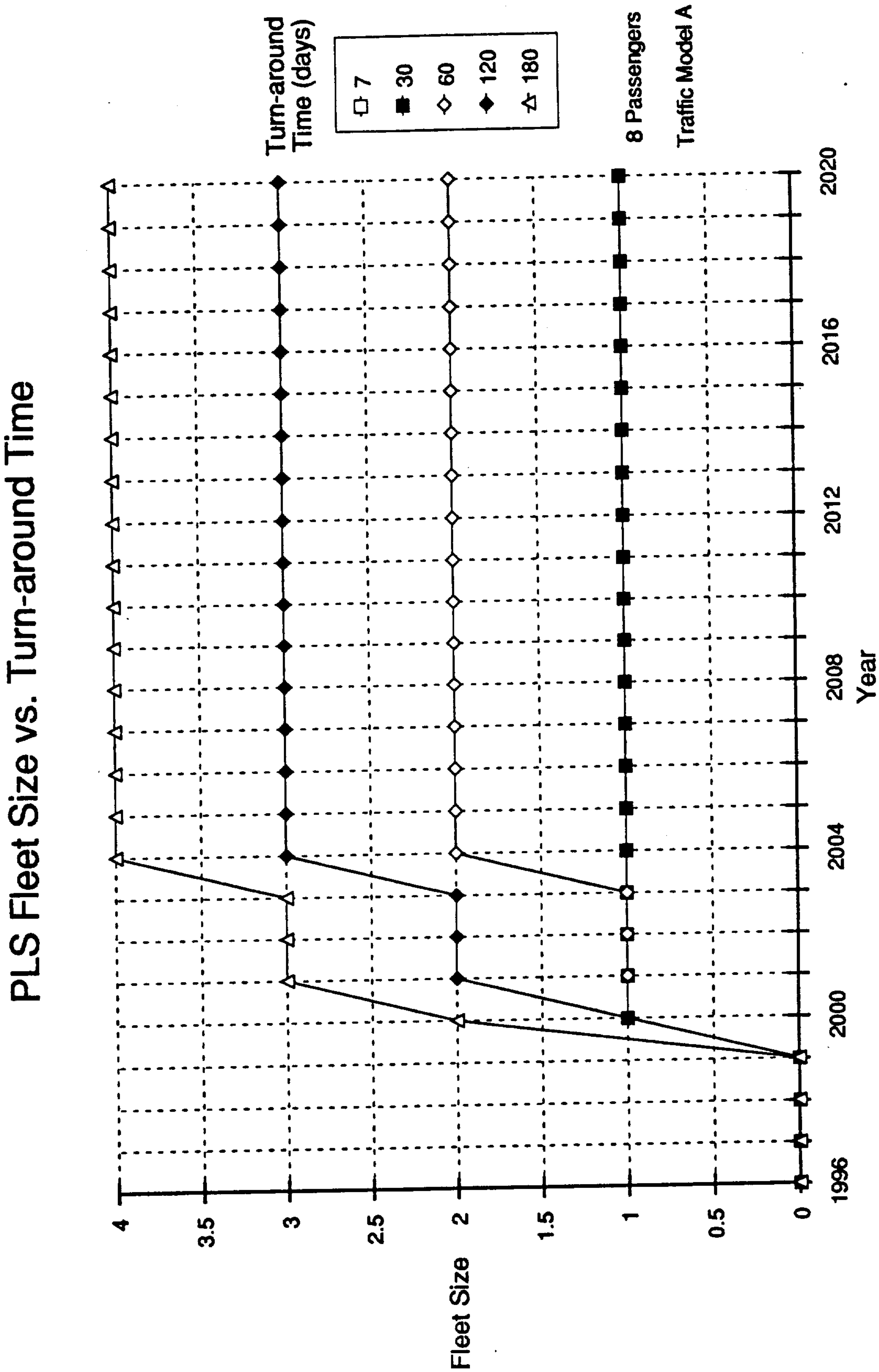
PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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120
180
8 Passengers
Traffic Model A
Fleet Size
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Year
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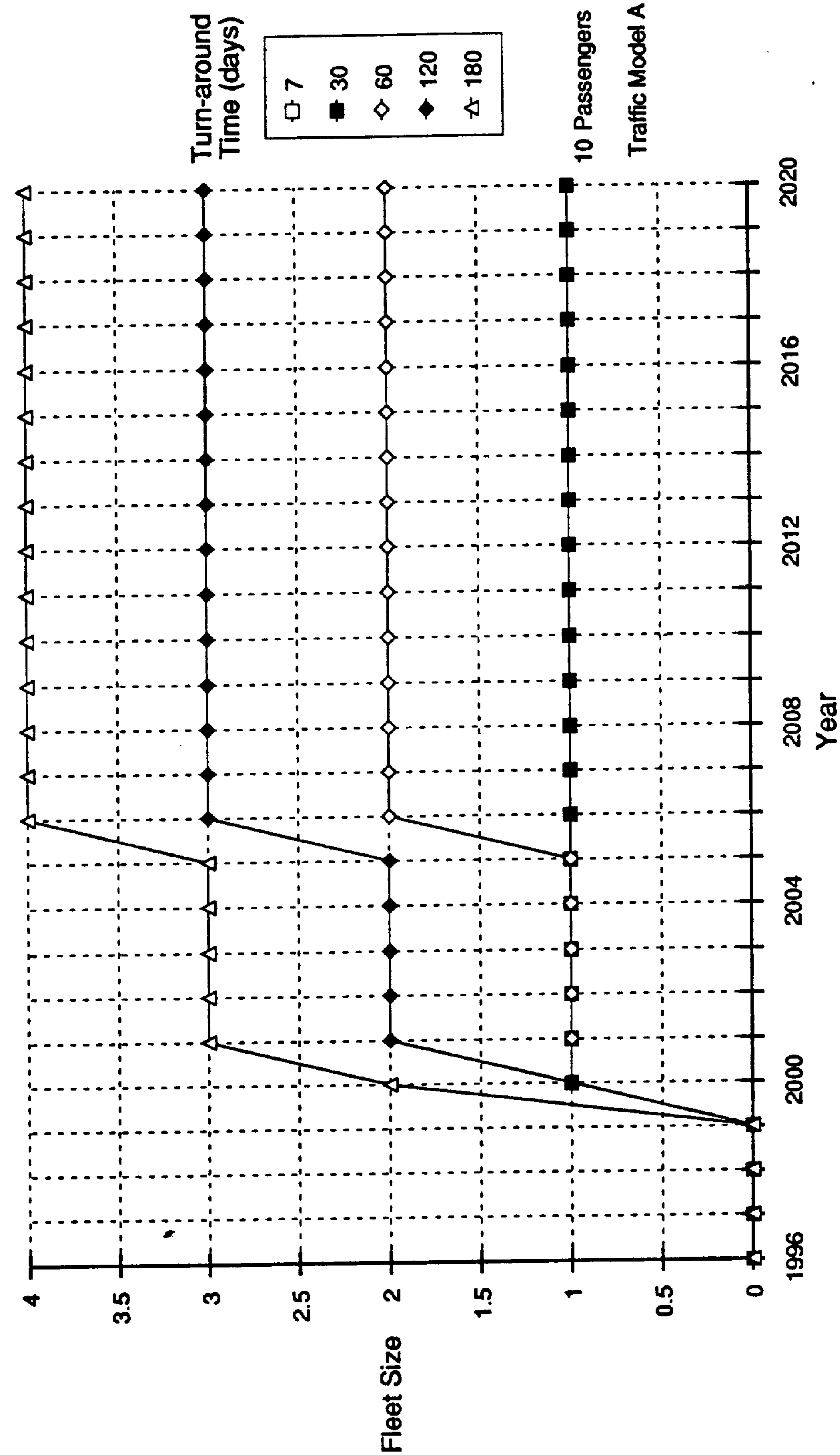
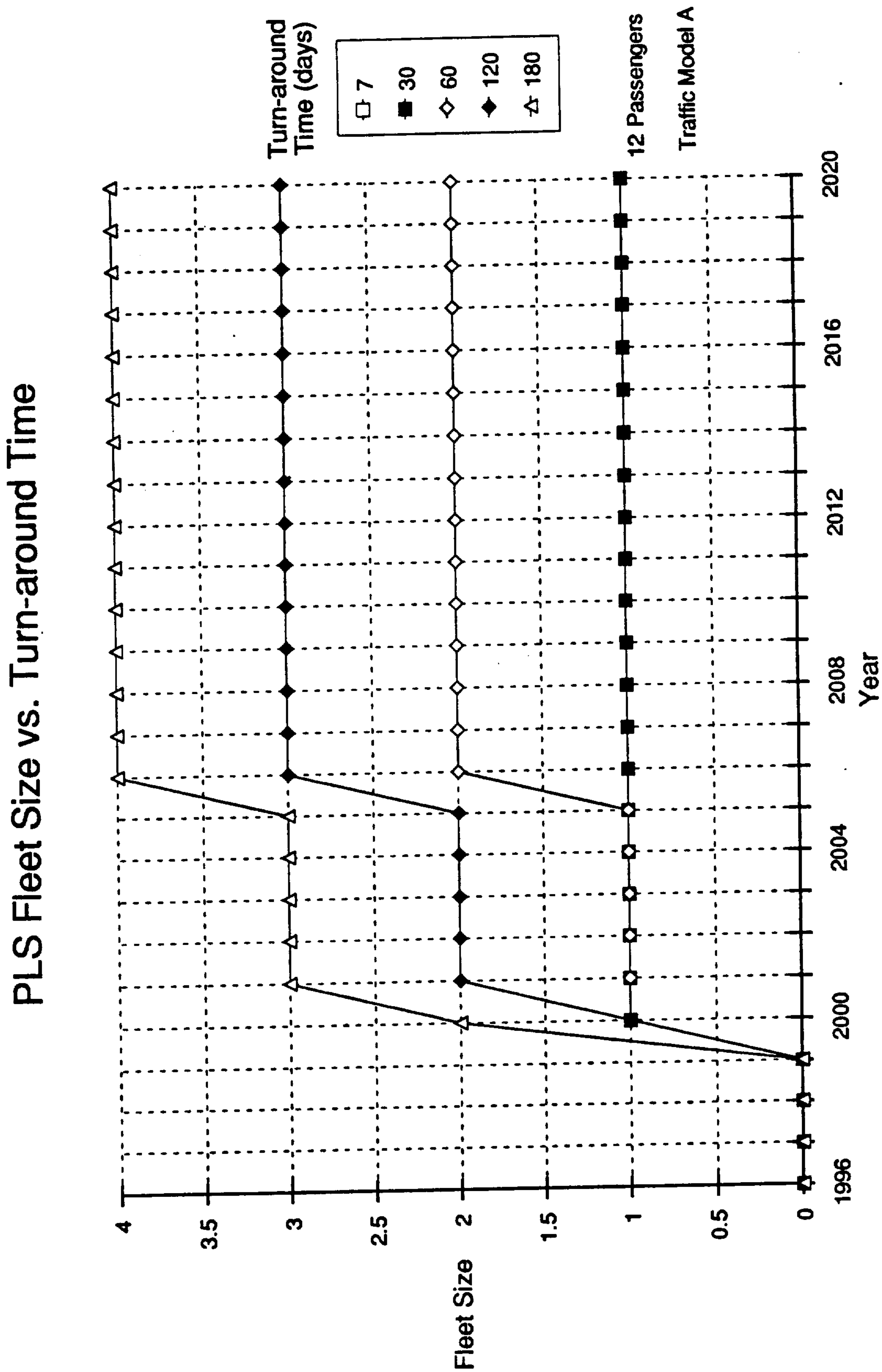
2016
2020

PLS Fleet Size vs. Turn-around Time




PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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120
180
12 Passengers
Traffic Model A
Fleet Size
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Year
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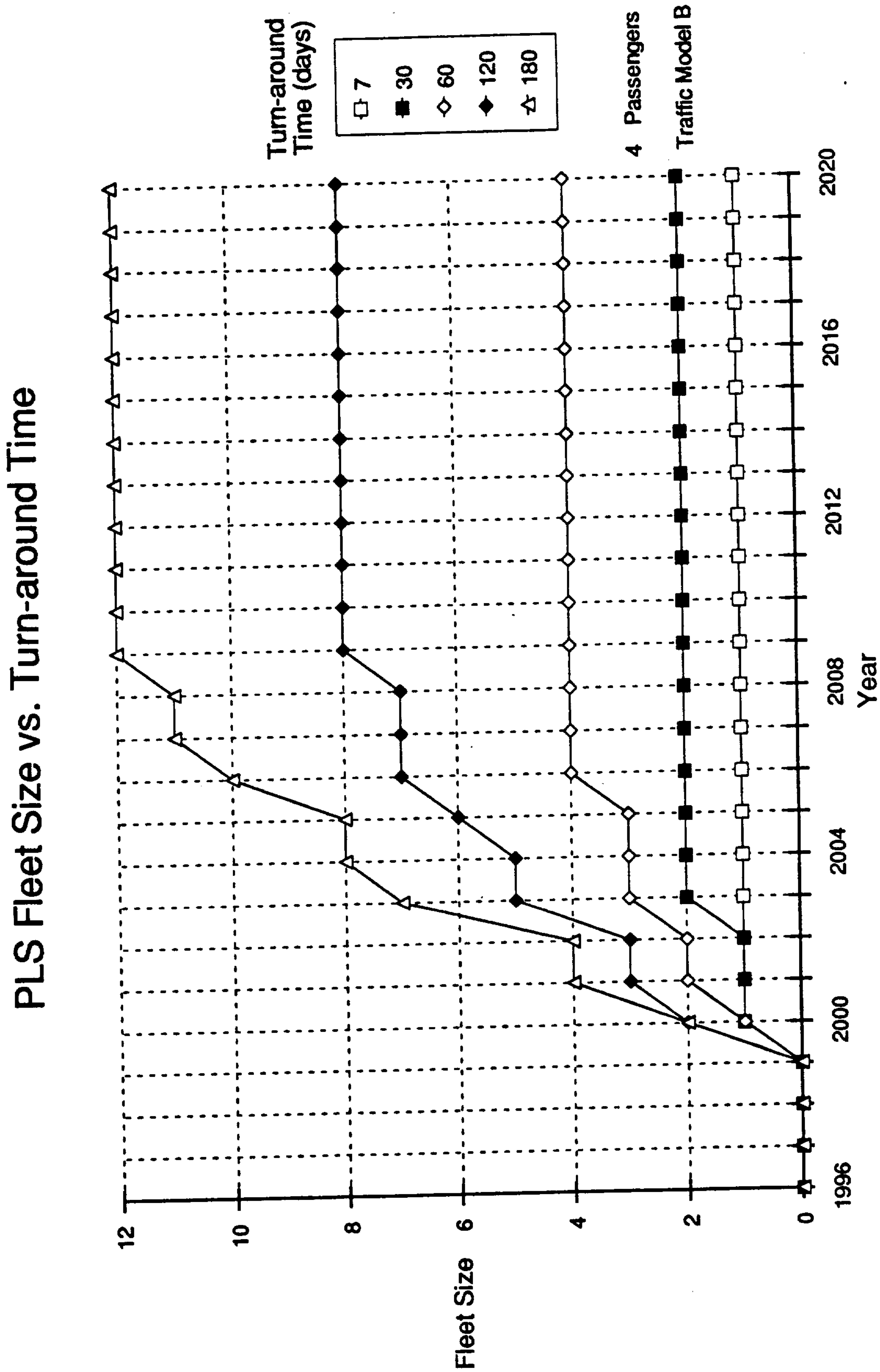
PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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180
4 Passengers
Traffic Model B
Fleet Size
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Year
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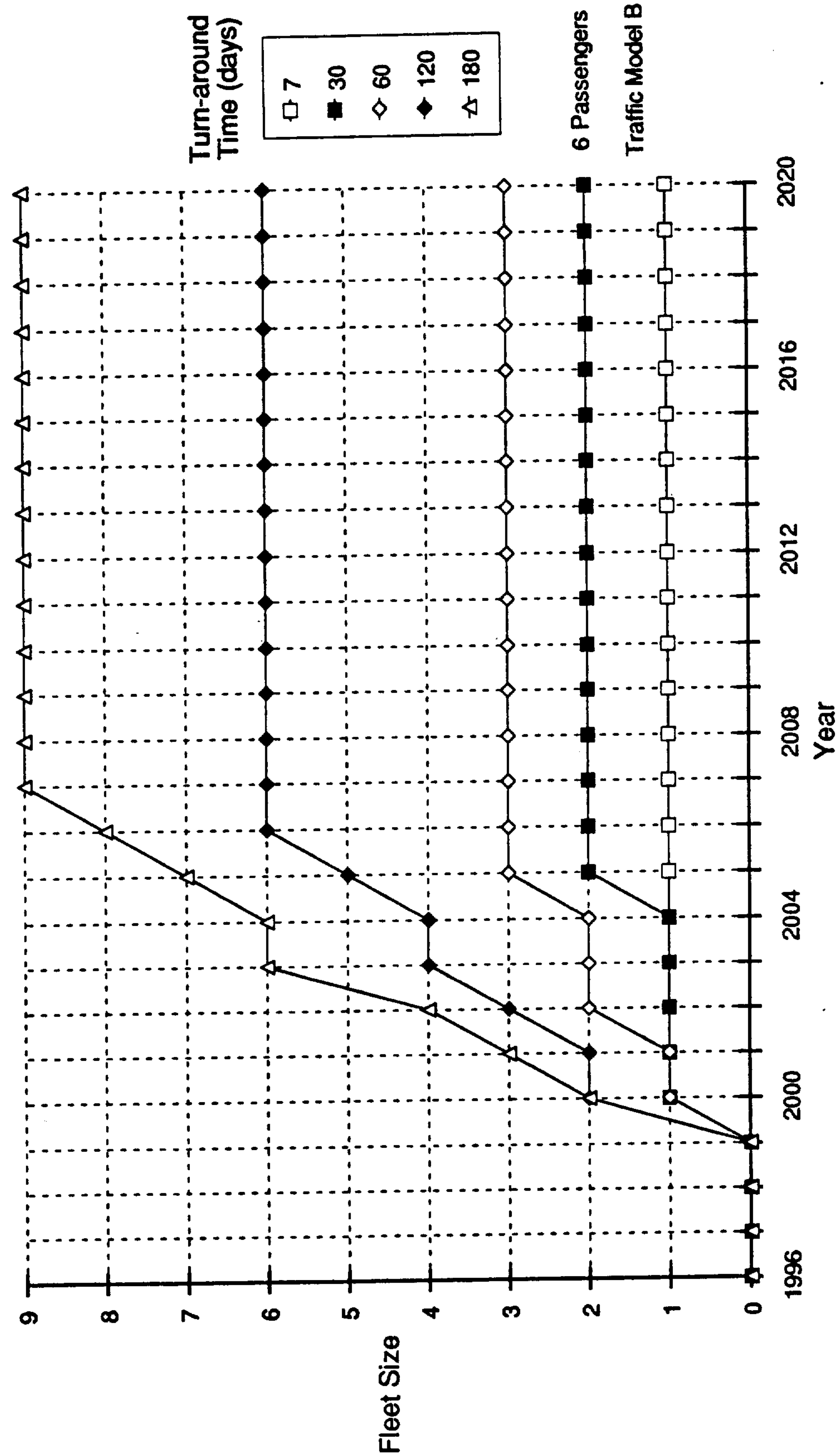
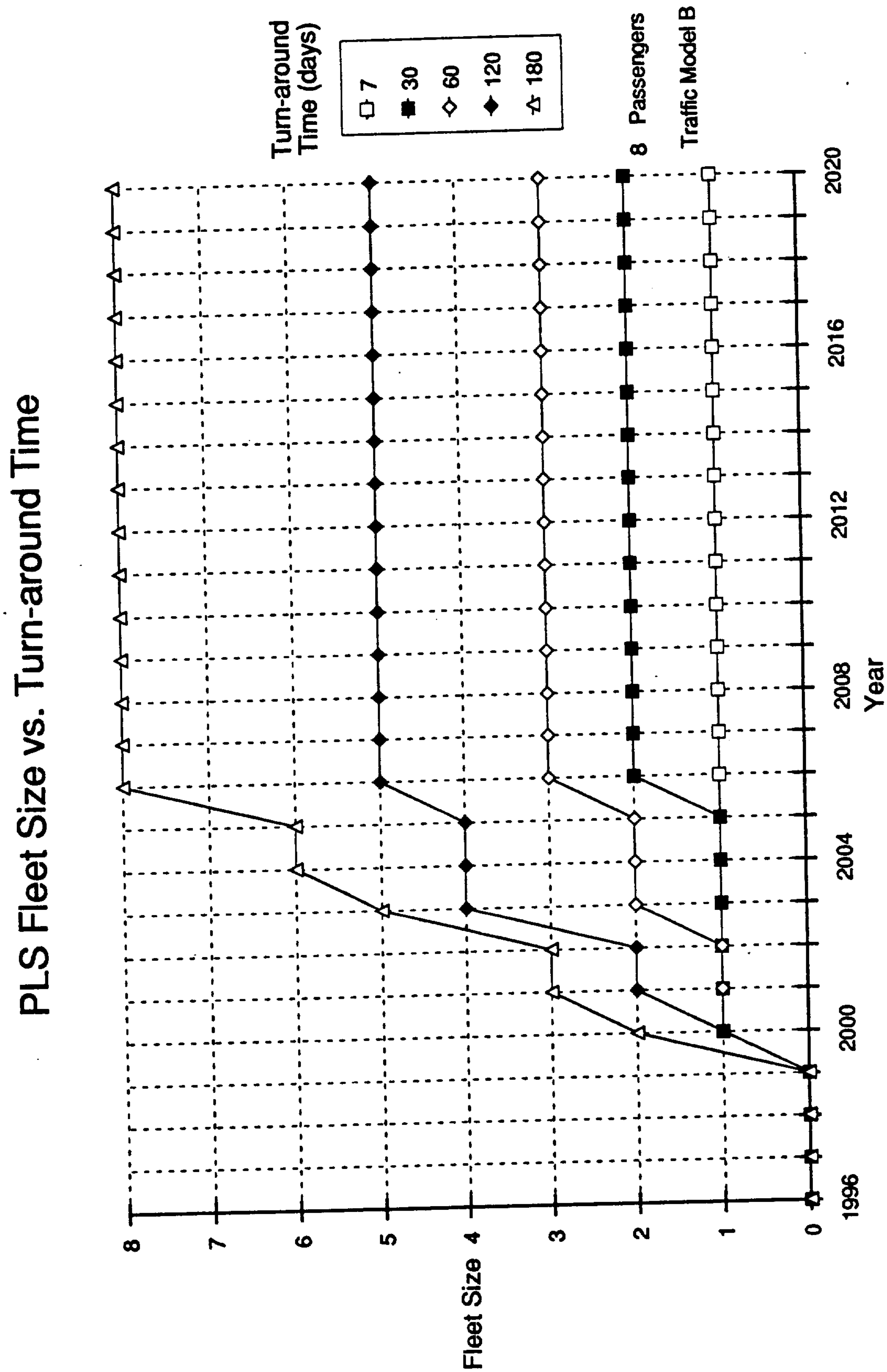
2020

PLS Fleet Size vs. Turn-around Time




PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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8 Passengers
Traffic Model B
Fleet Size
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Year
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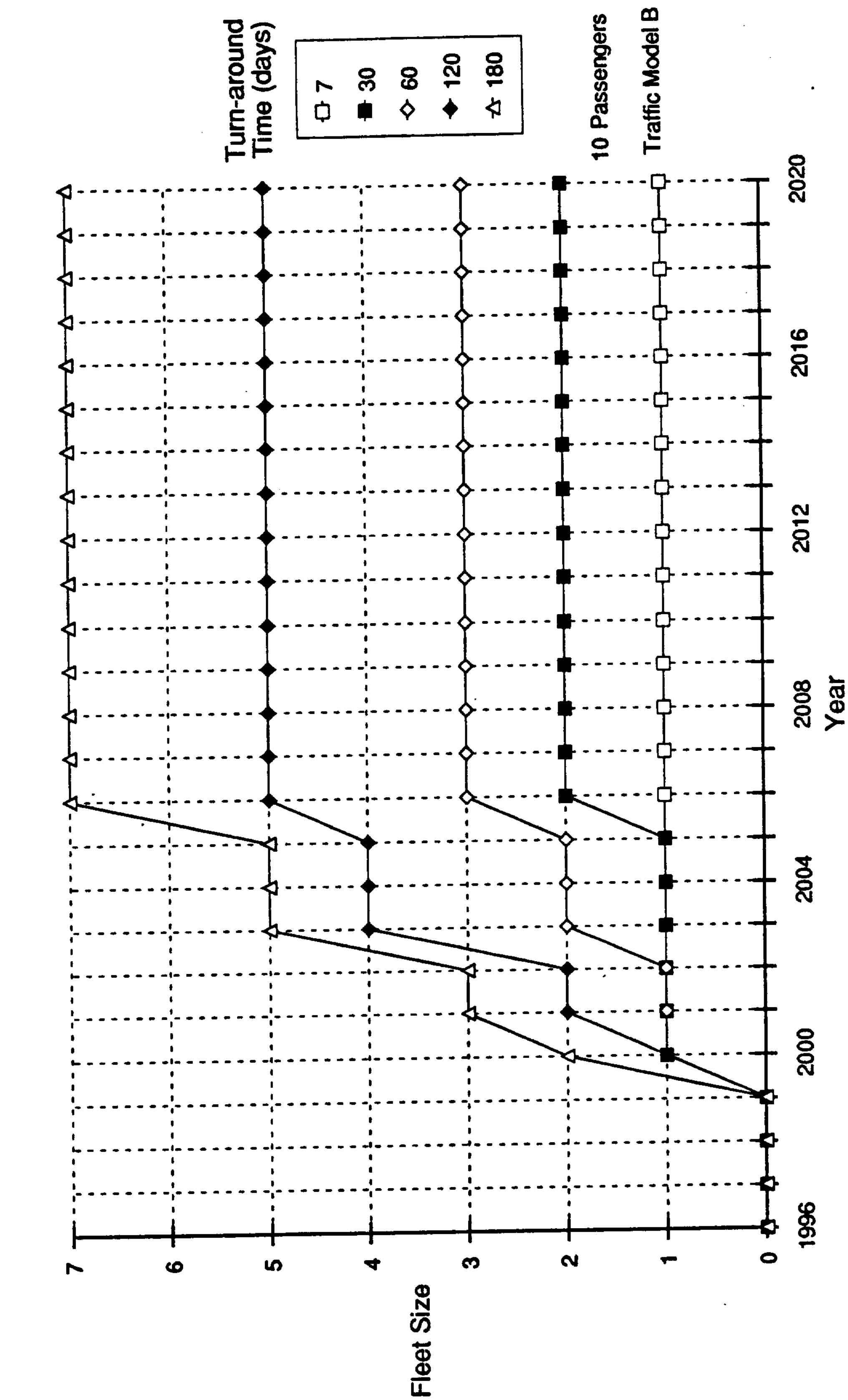
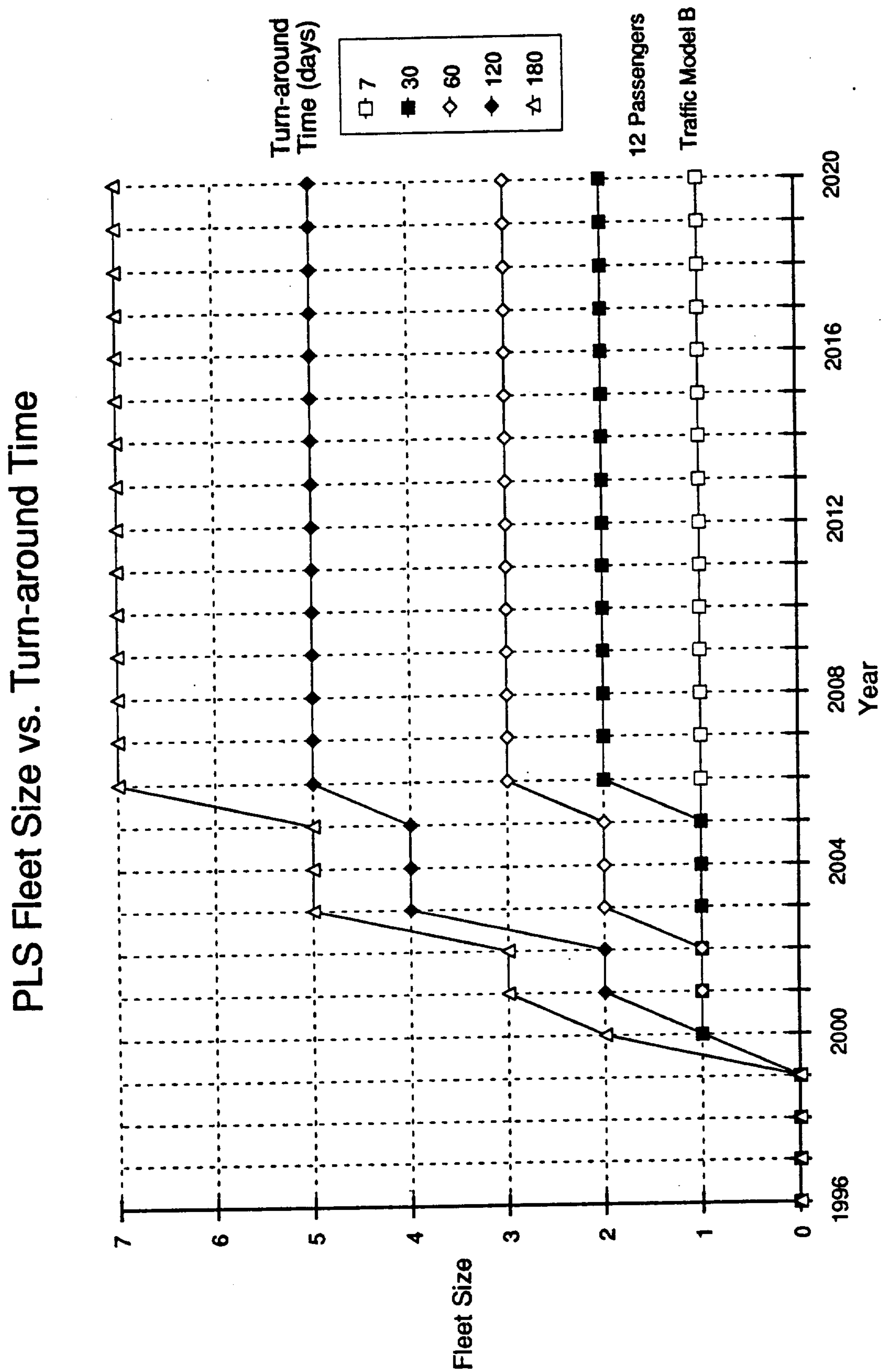
PLS Fleet Size vs. Turn-around Time




PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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12 Passengers
Traffic Model B
Fleet Size
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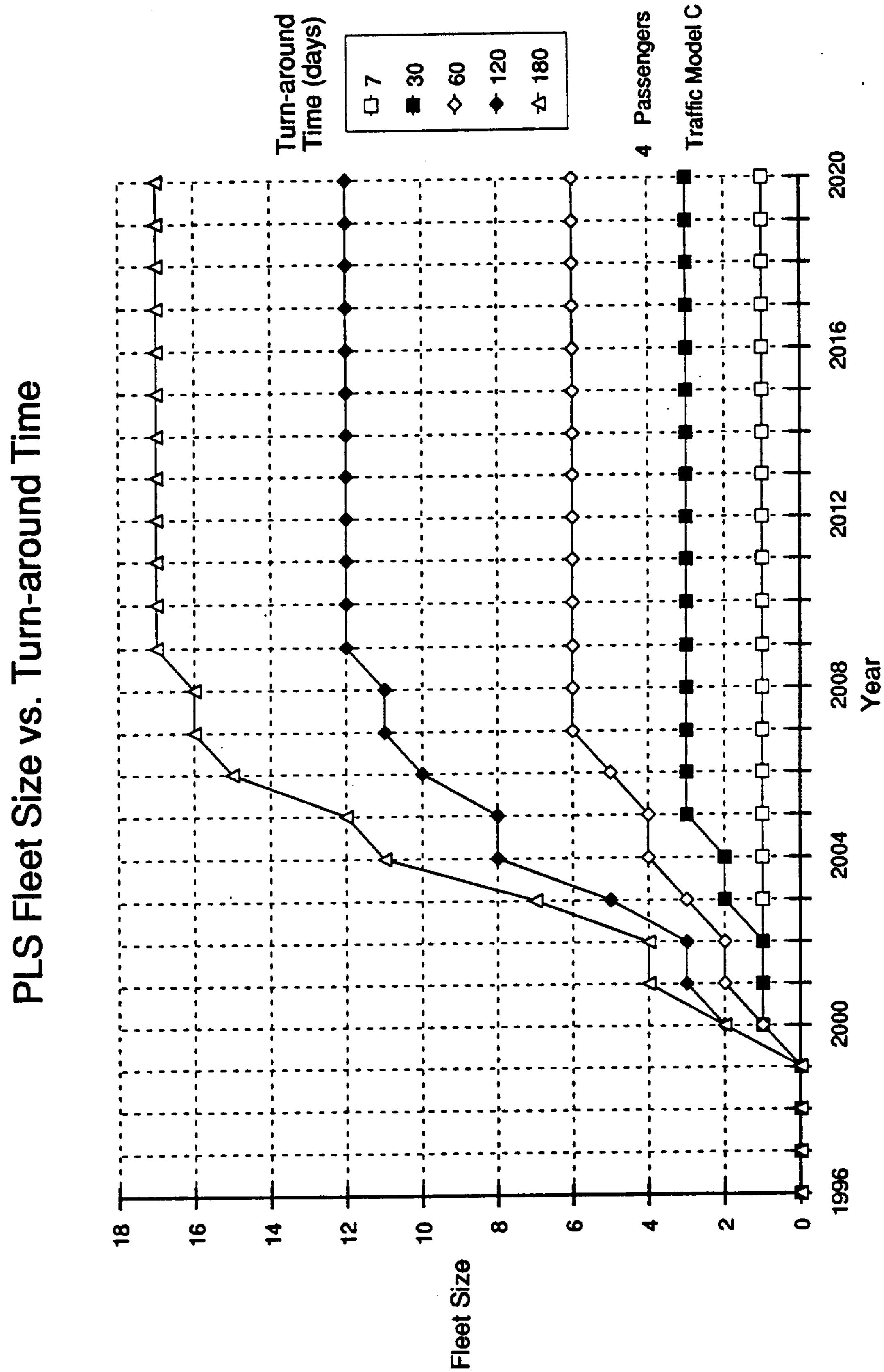
PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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180
4 Passengers
Traffic Model C
Fleet Size
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2016
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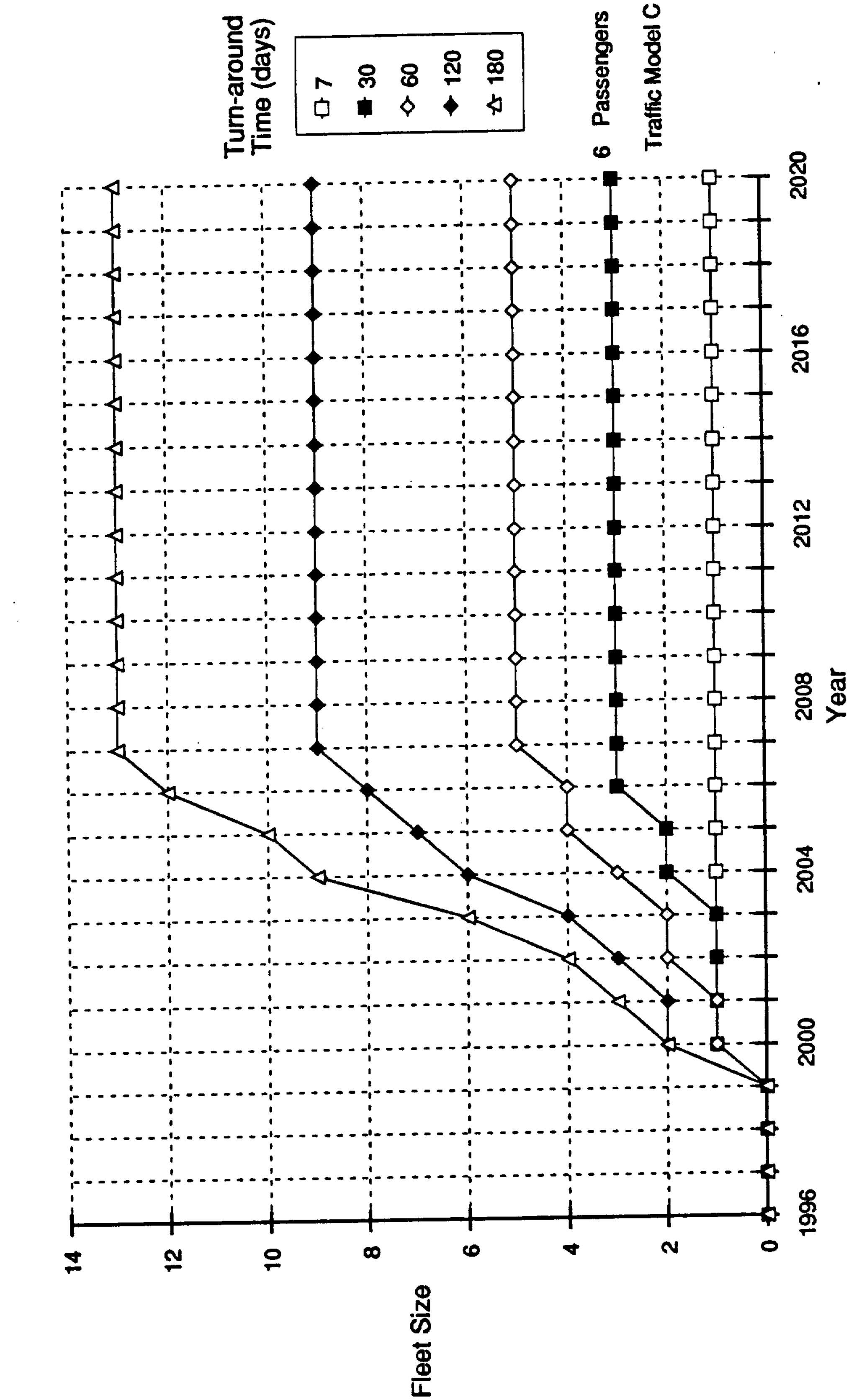
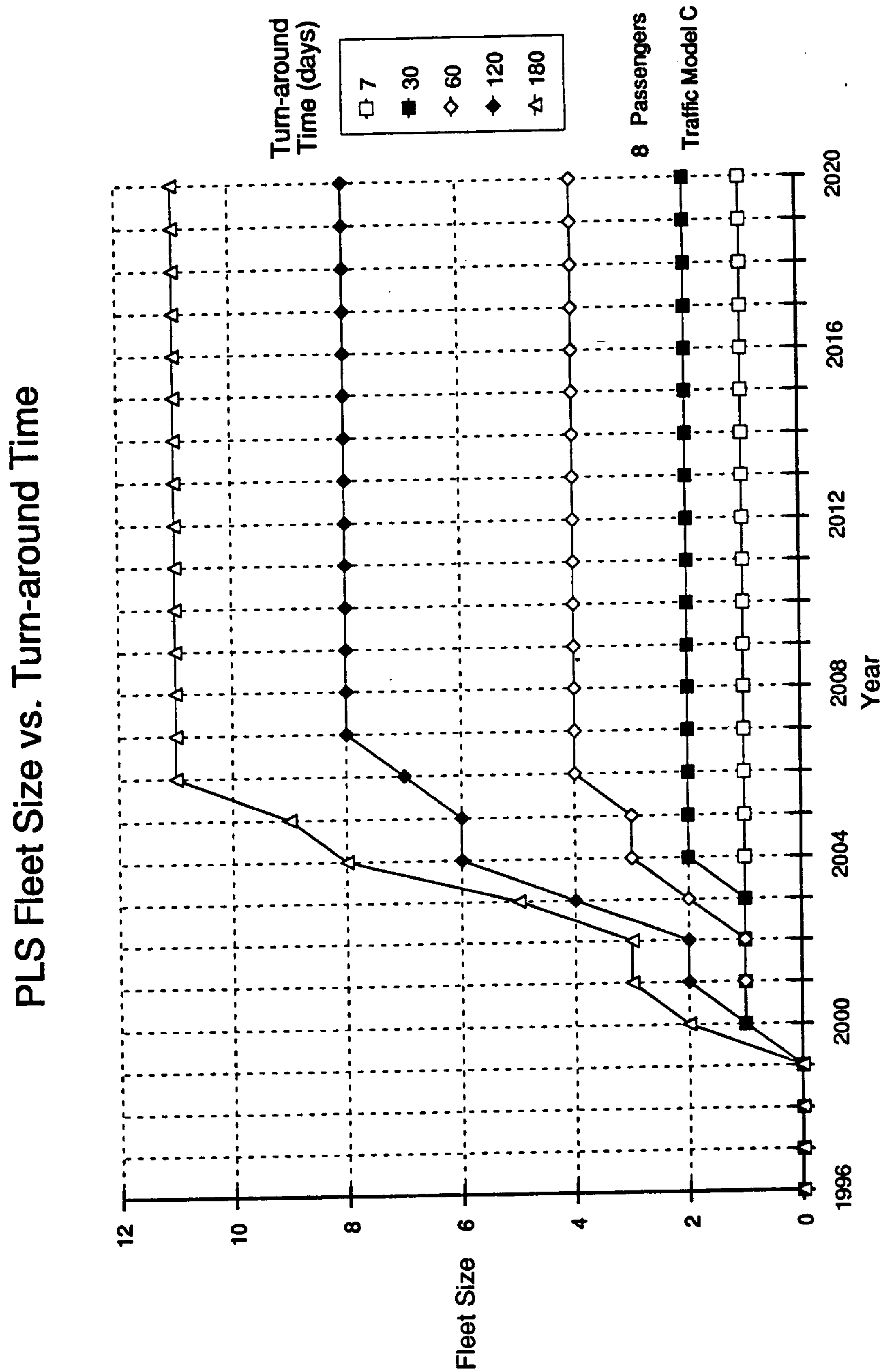
PLS Fleet Size vs. Turn-around Time




PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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180
8 Passengers
Traffic Model C
Fleet Size
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Year
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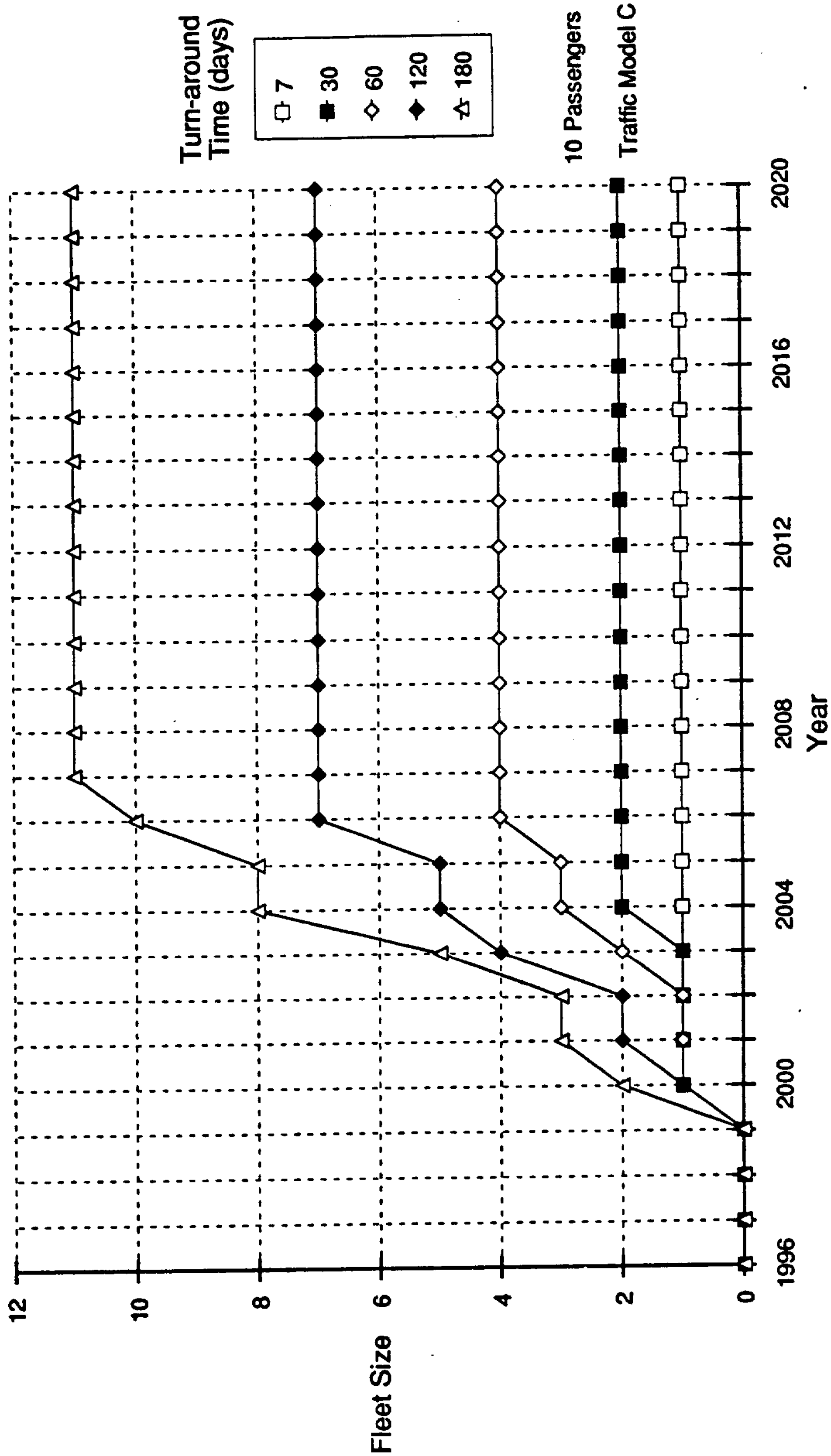
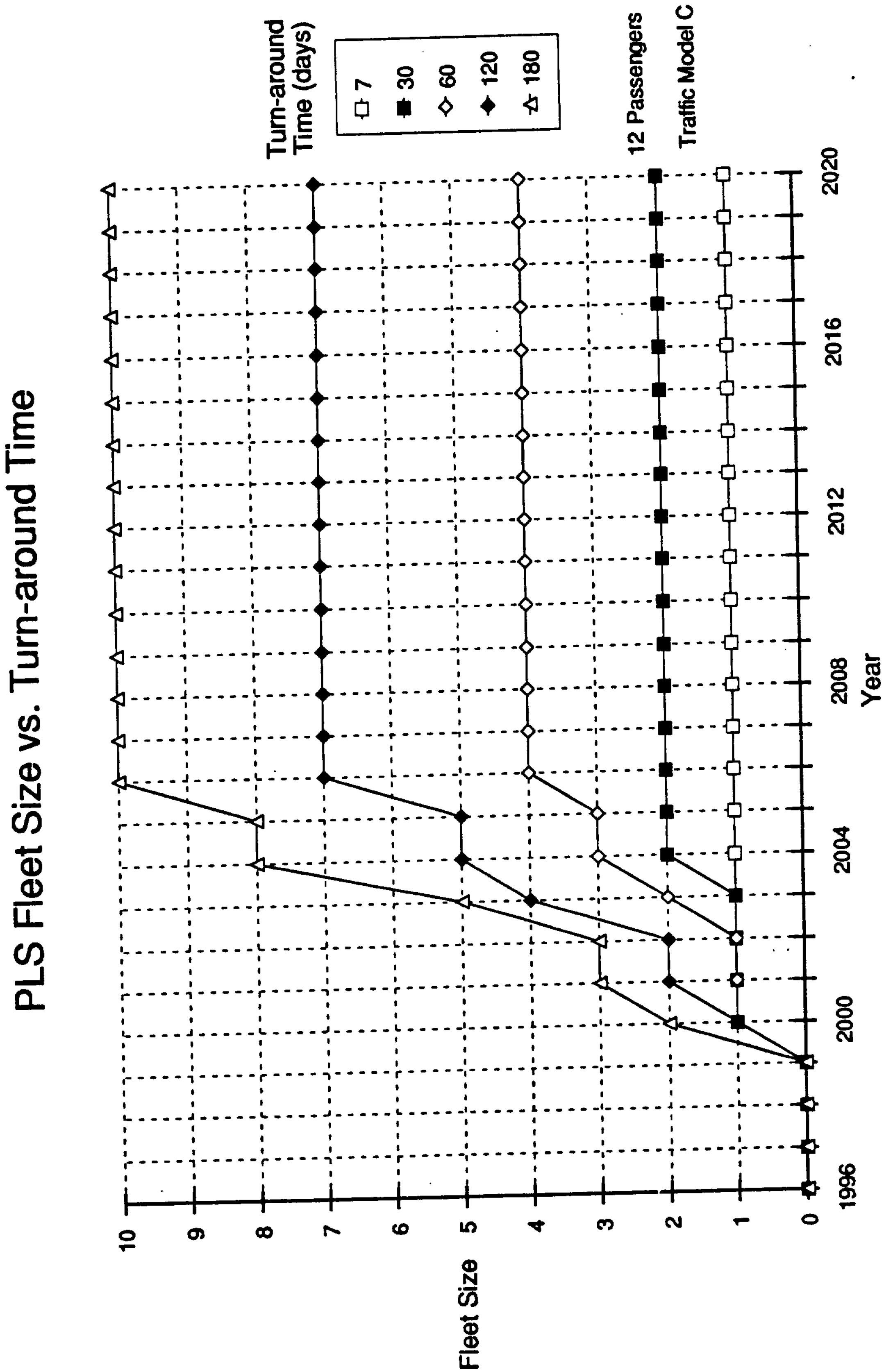
PLS Fleet Size vs. Turn-around Time




PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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120
180
12 Passengers
Traffic Model C
Fleet Size
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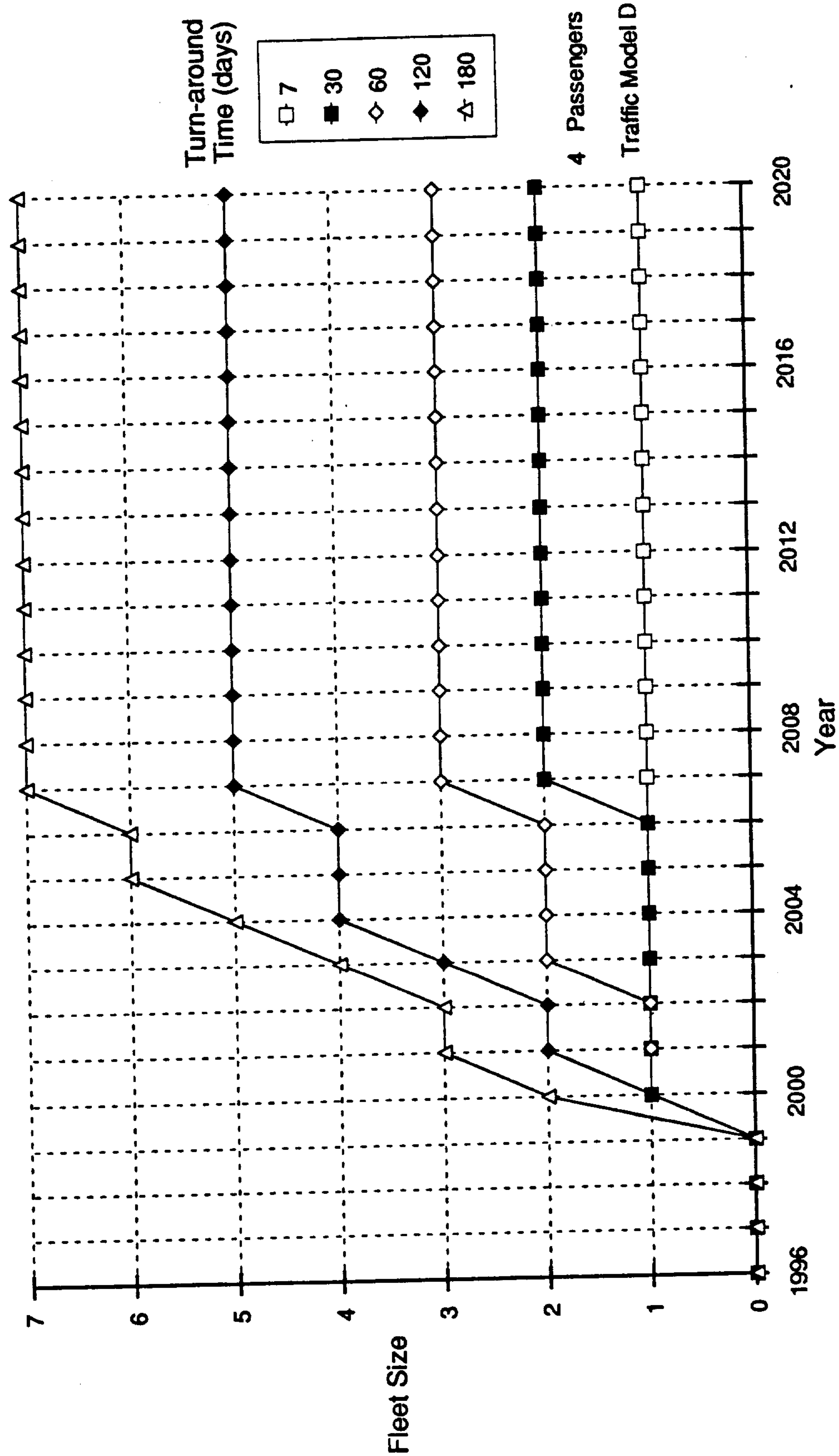
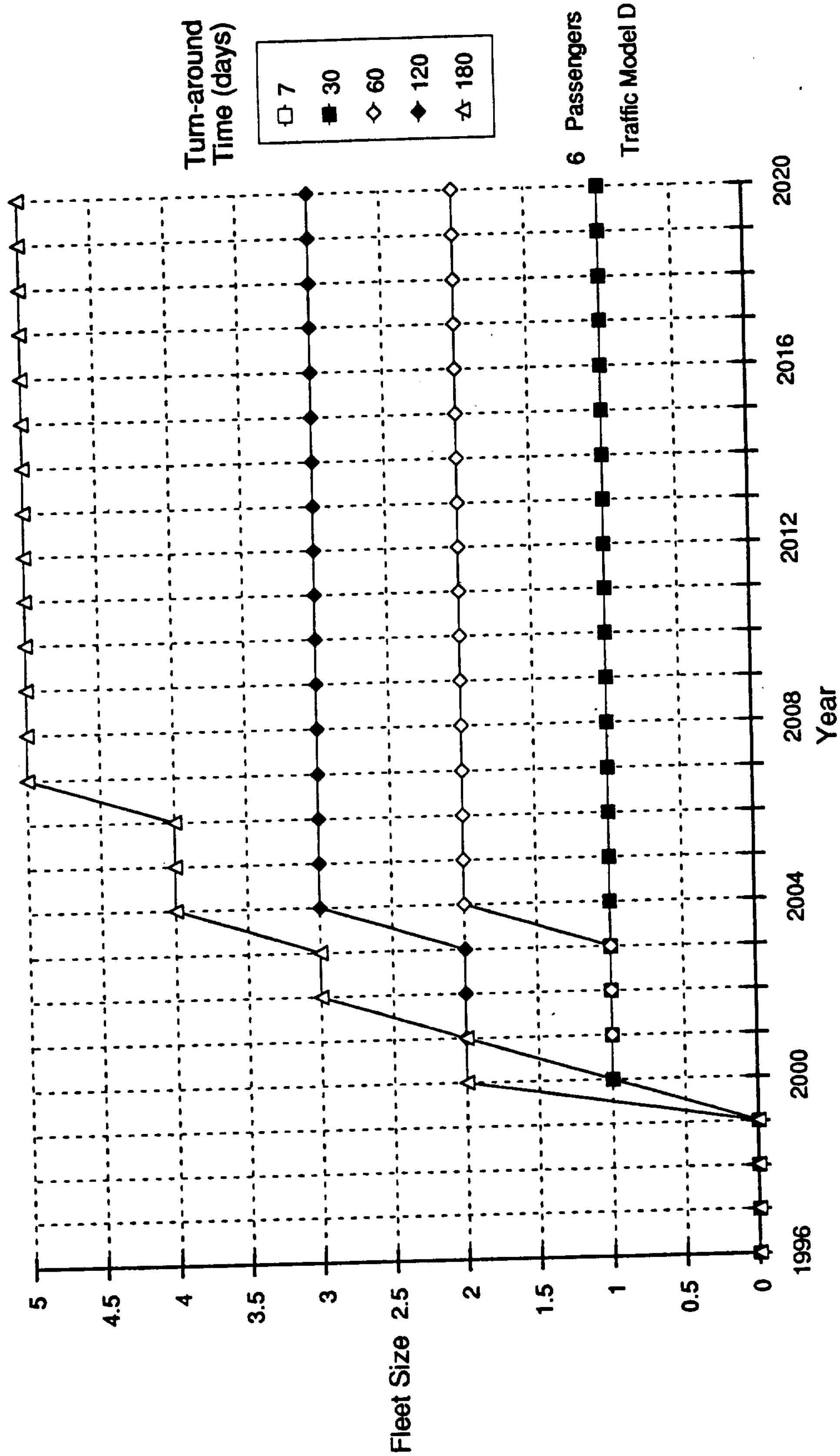
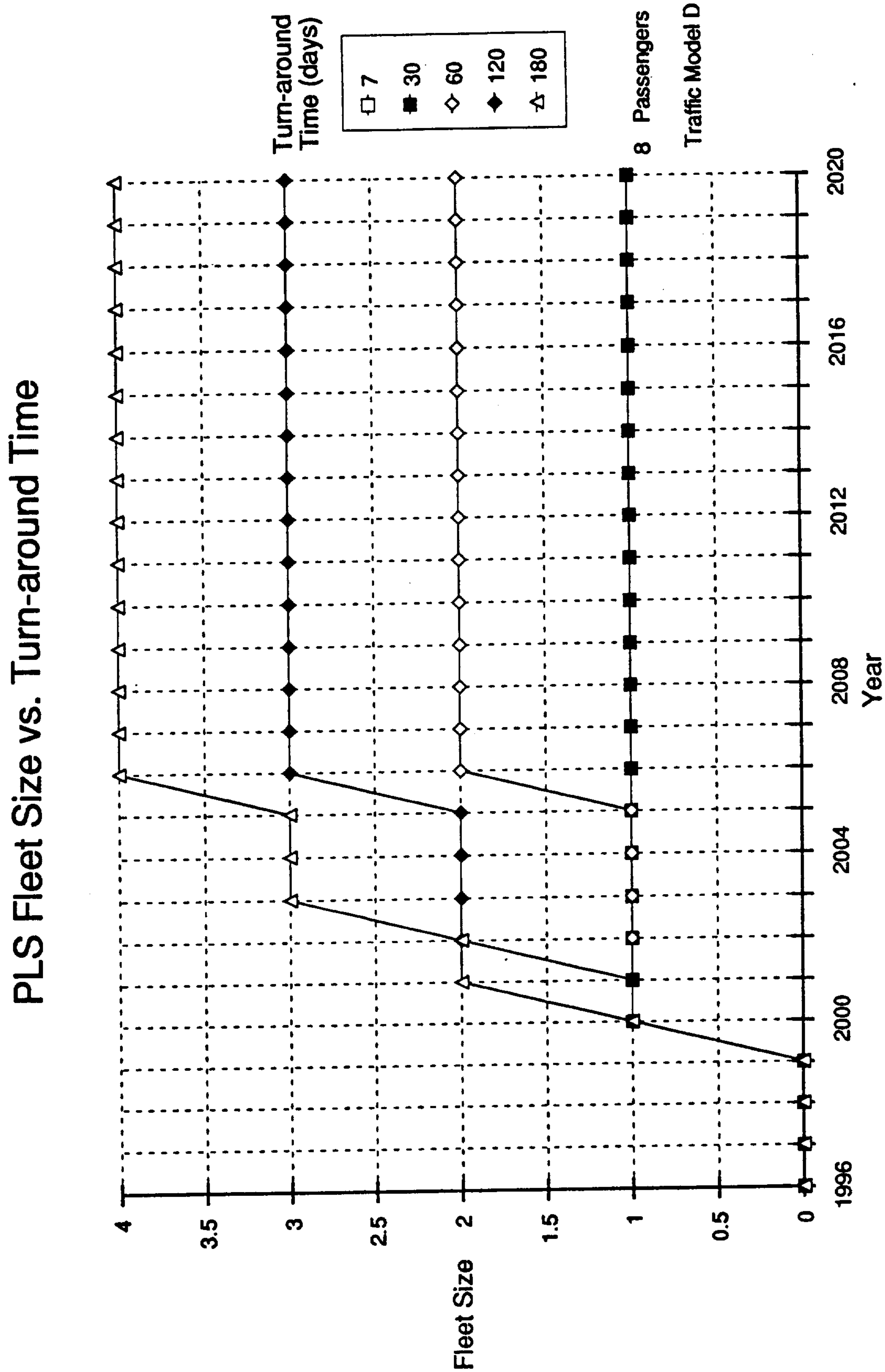
Year

PLS Fleet Size vs. Turn-around Time



PLS Fleet Size vs. Turn-around Time




PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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60
120
180
8 Passengers
Traffic Model D
Fleet Size
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4
Year
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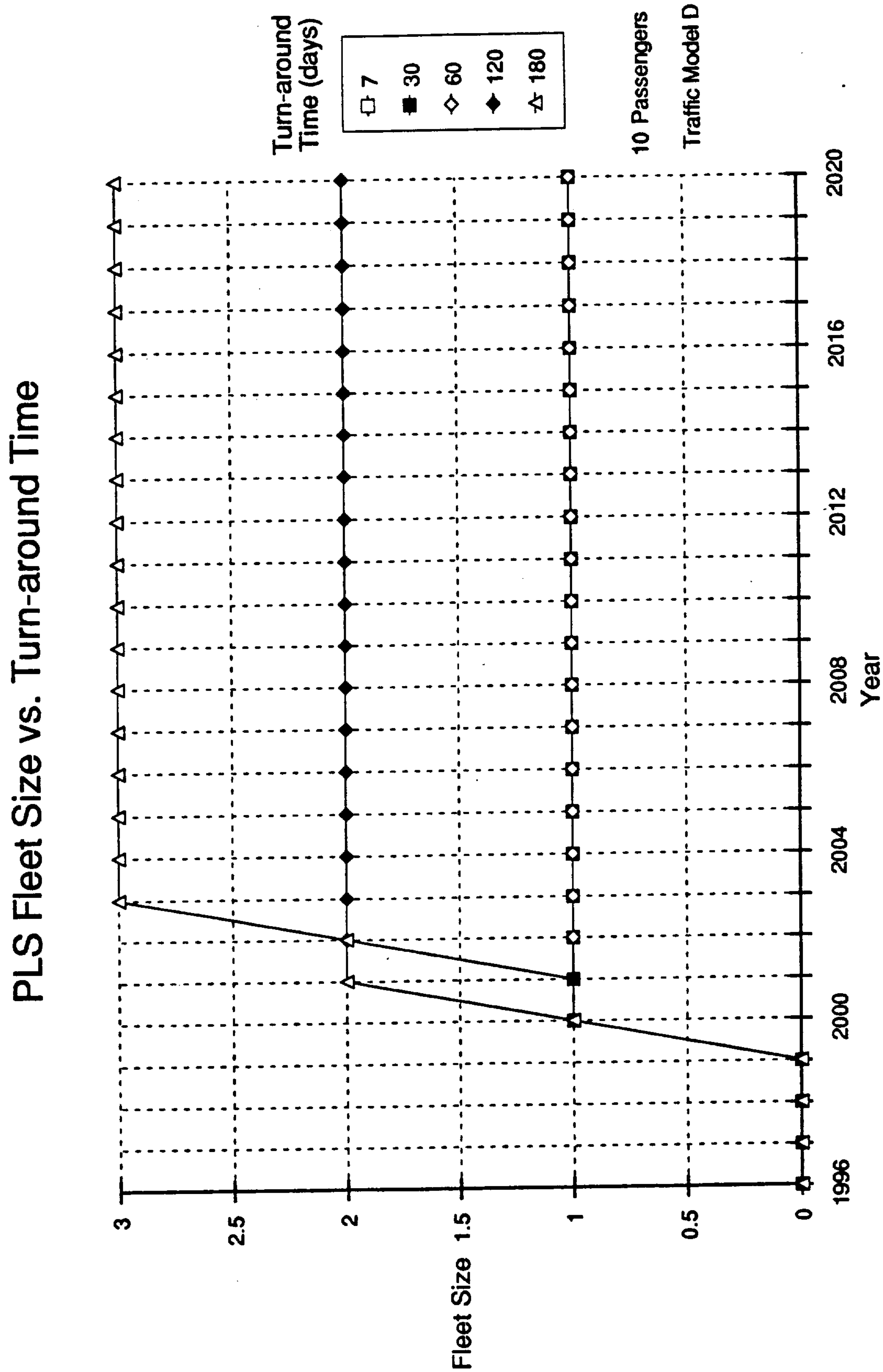
PLS Fleet Size vs. Turn-around Time
Fleet Size
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1
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Year
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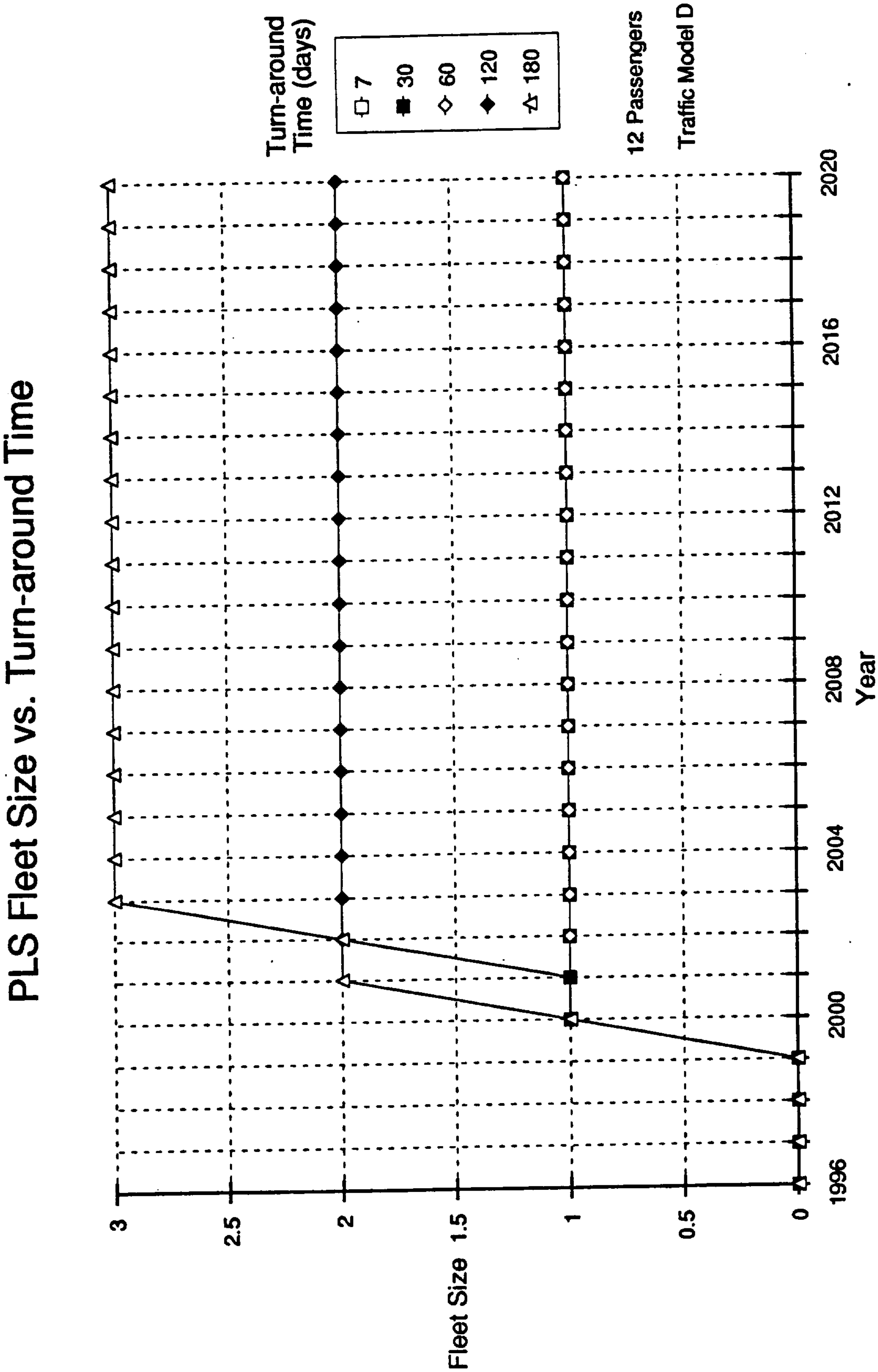
2016
2020
Turn-around Time (days)
7
30
60
120
180
10 Passengers
Traffic Model D


PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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180
12 Passengers
Traffic Model D
Fleet Size
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Year
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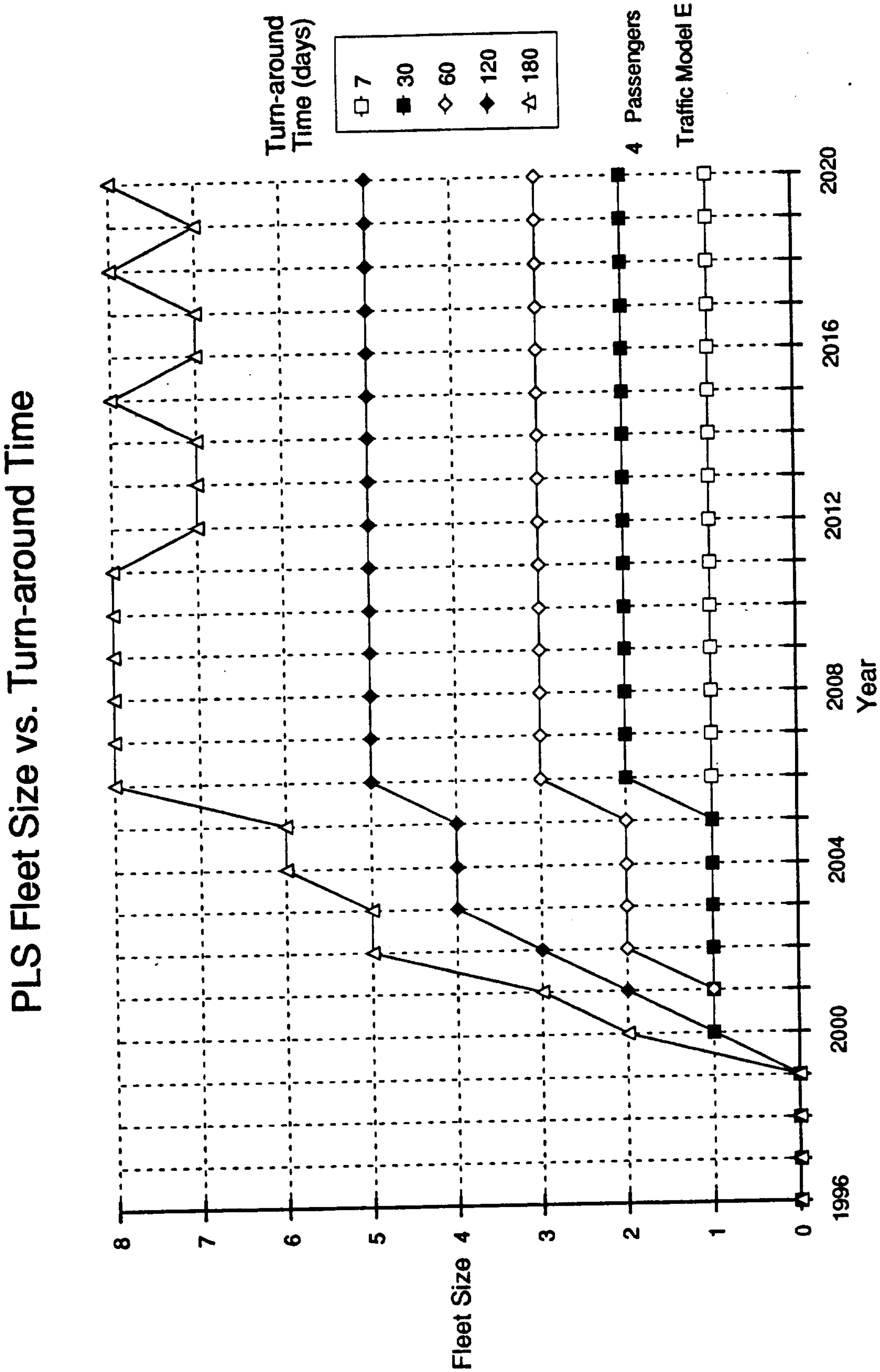
PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
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180
4 Passengers
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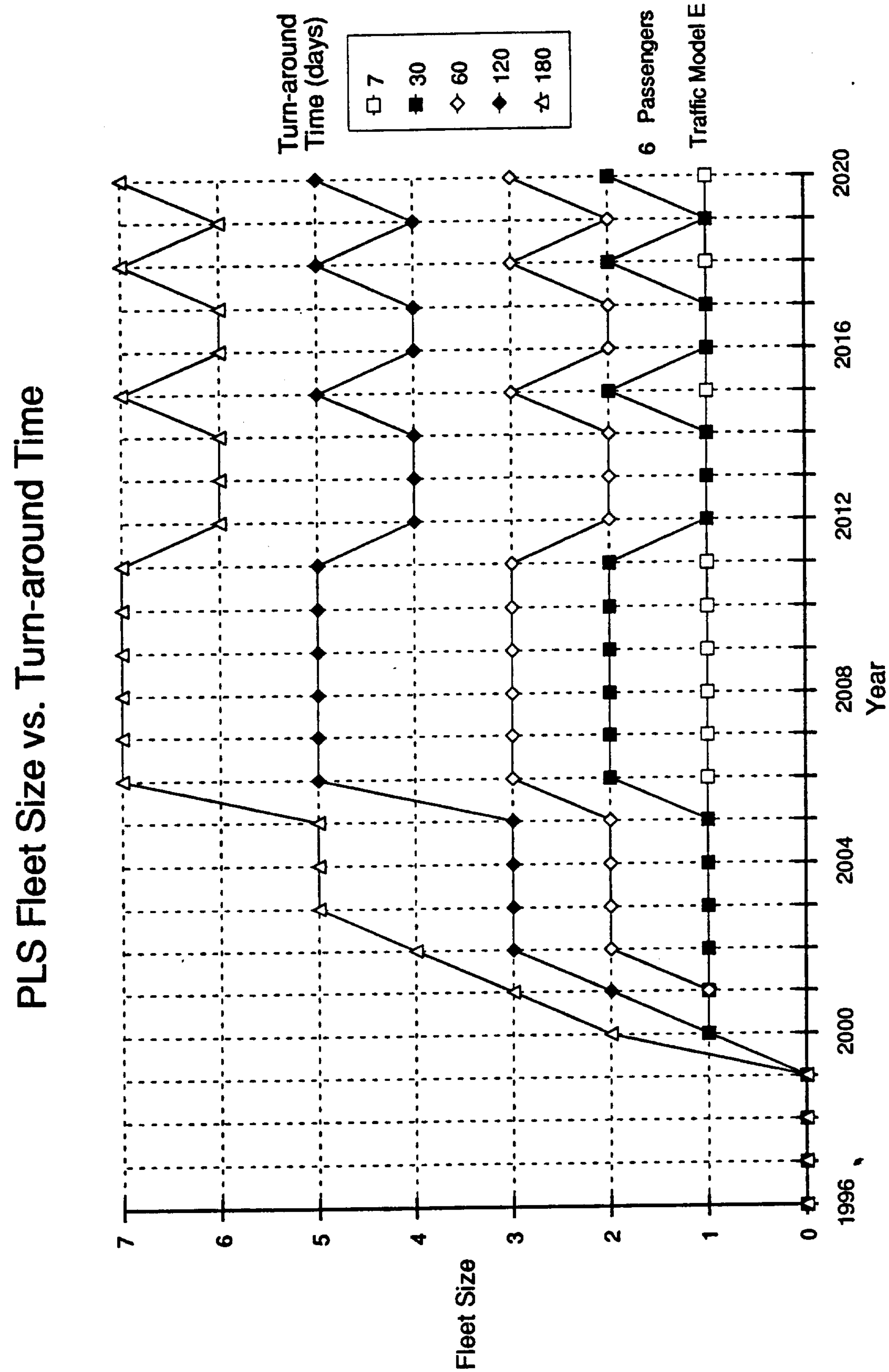
PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
7
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120
180
6 Passengers
Traffic Model E
Fleet Size
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Year
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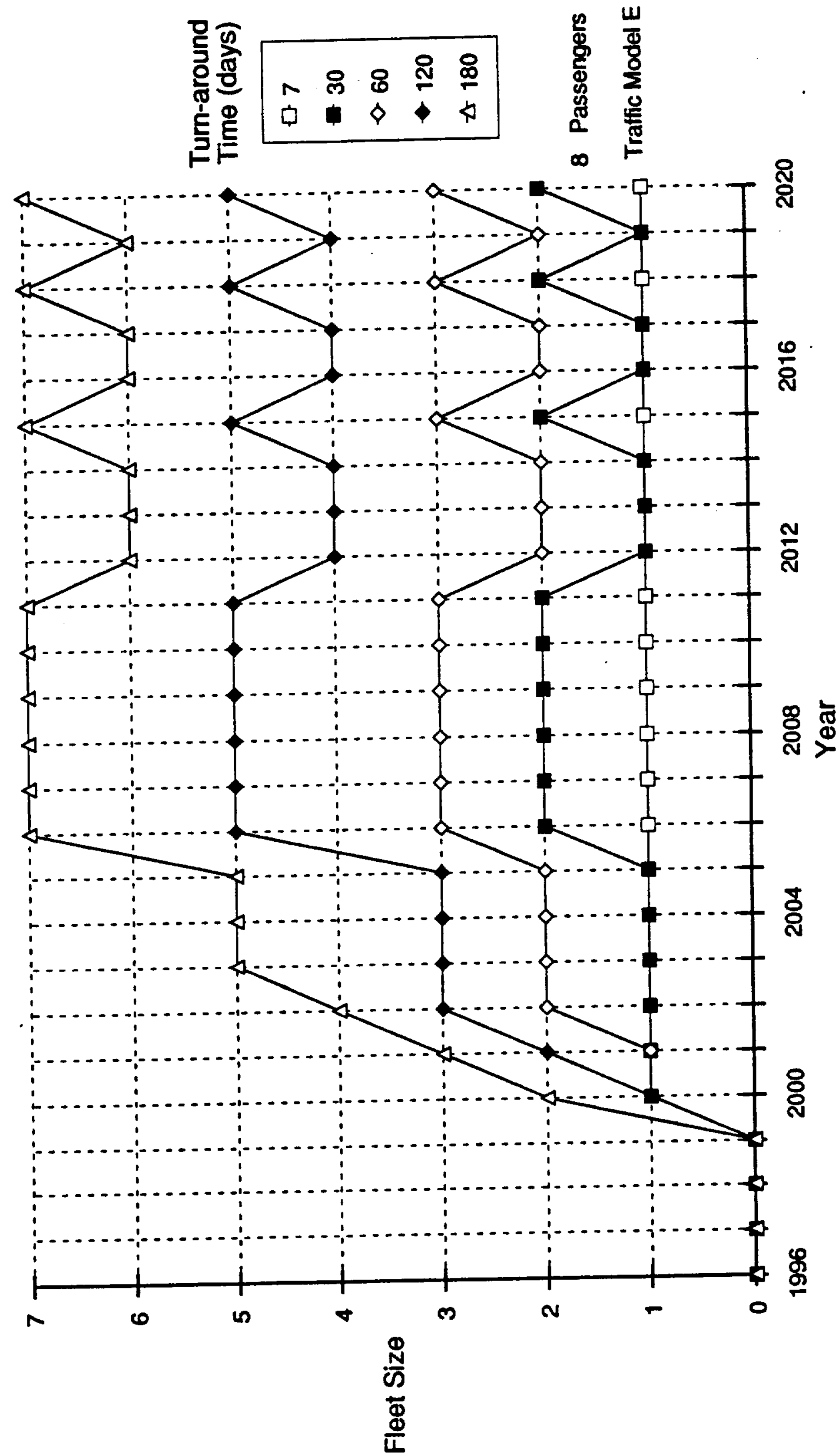
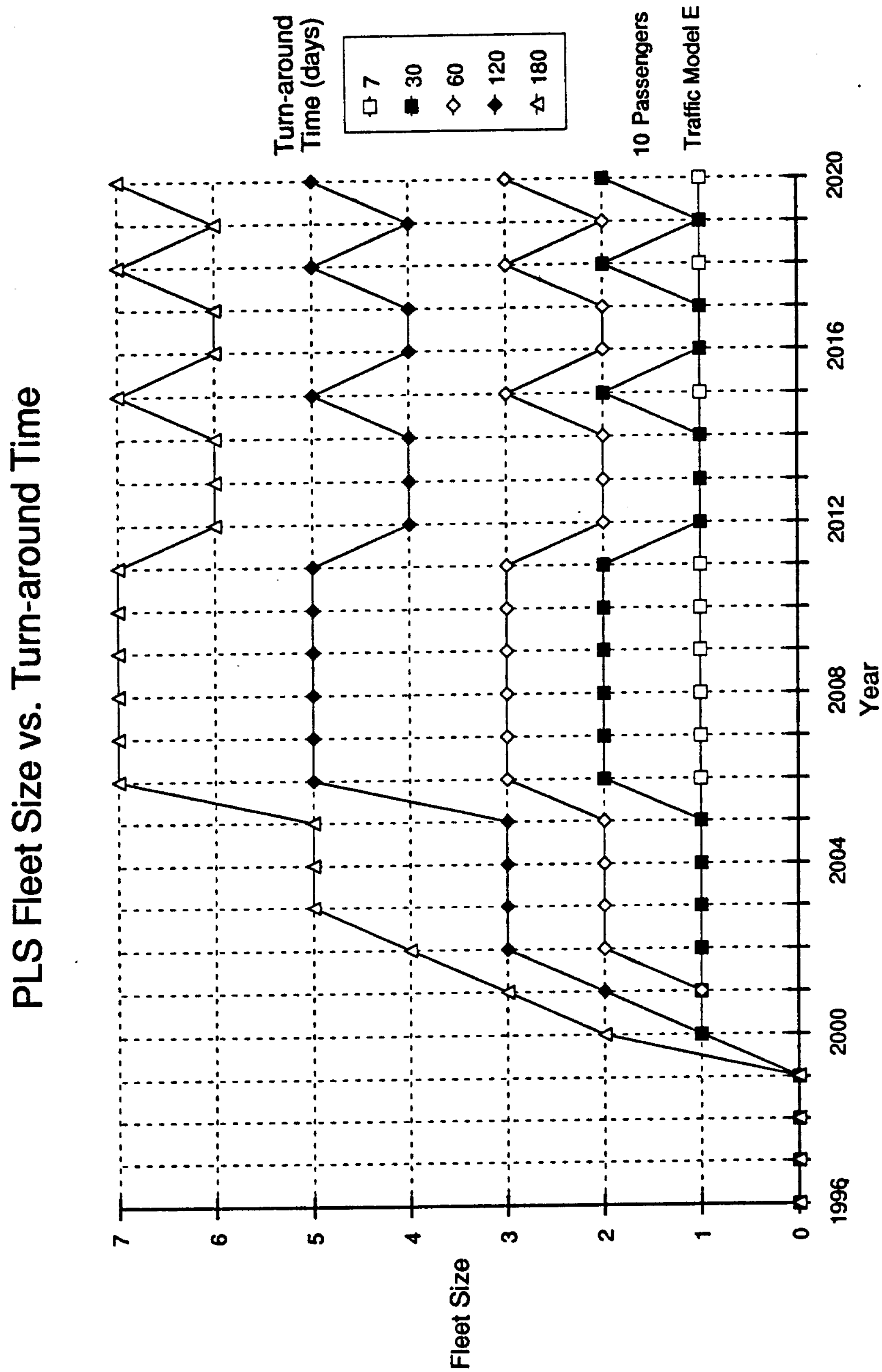
PLS Fleet Size vs. Turn-around Time




PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
7
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120
180
10 Passengers
Traffic Model E
Fleet Size
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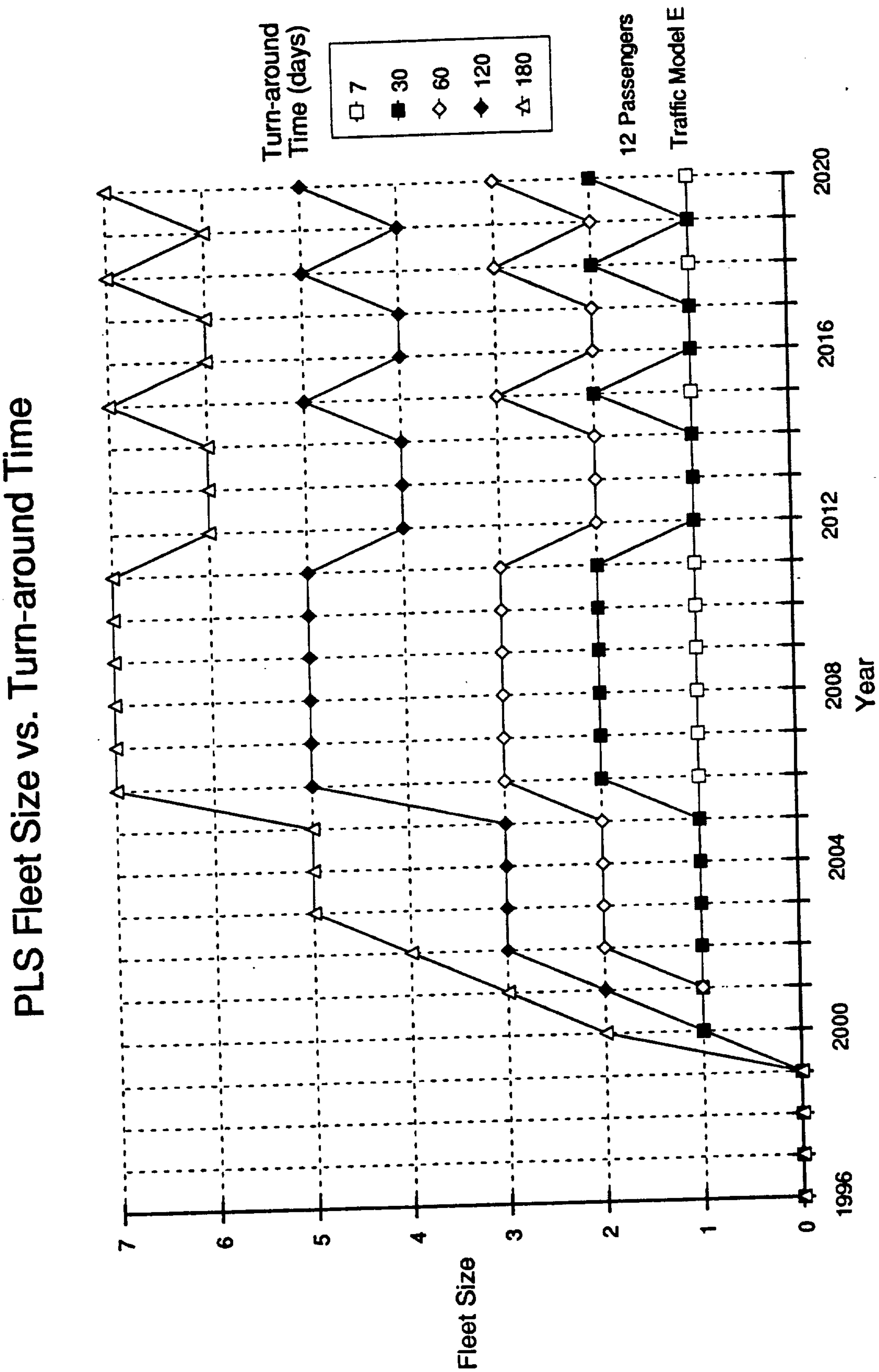
Year


PLS Fleet Size vs. Turn-around Time
Turn-around Time (days)
7
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60
120
180
12 Passengers
Traffic Model E
Fleet Size
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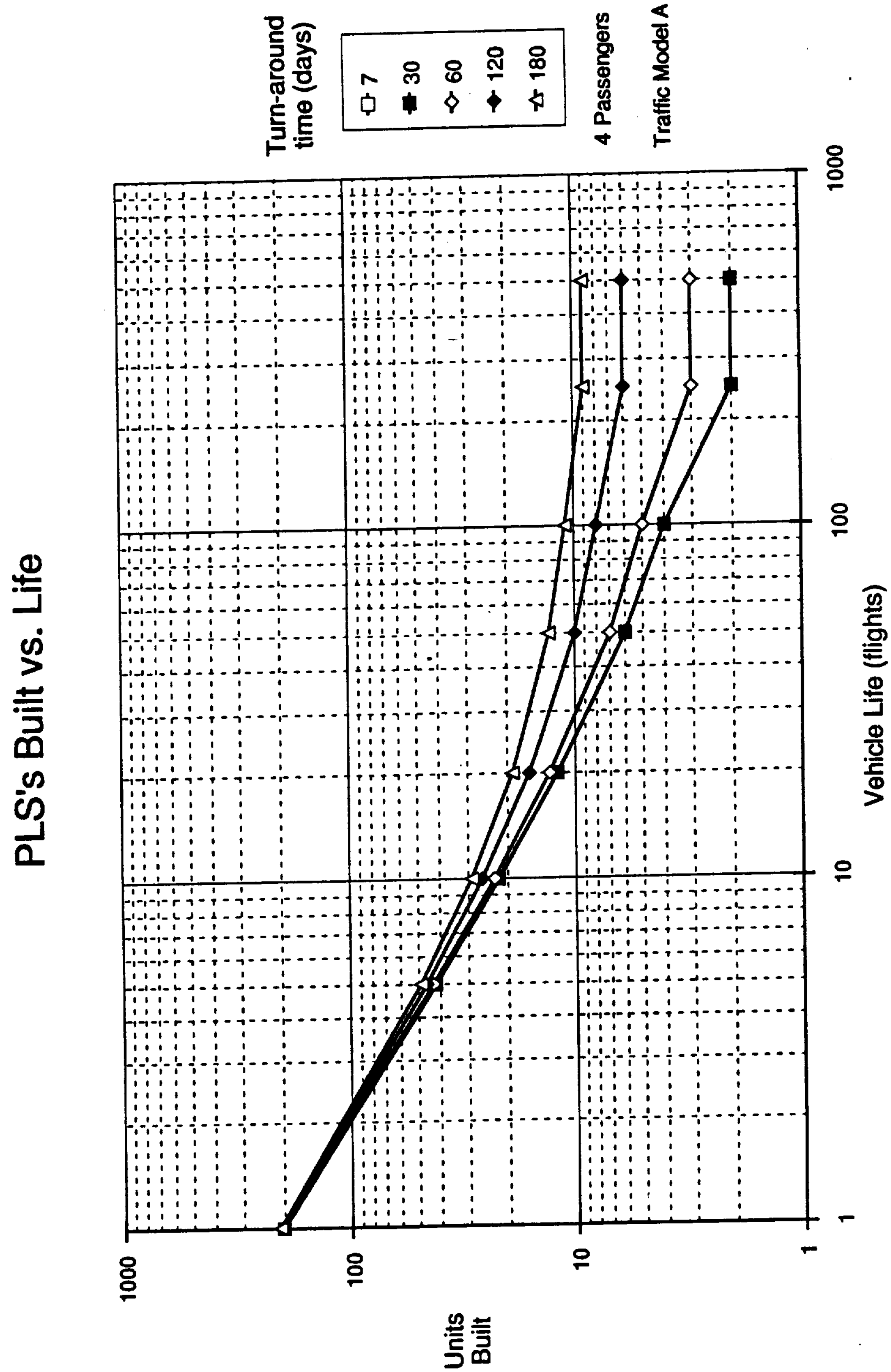
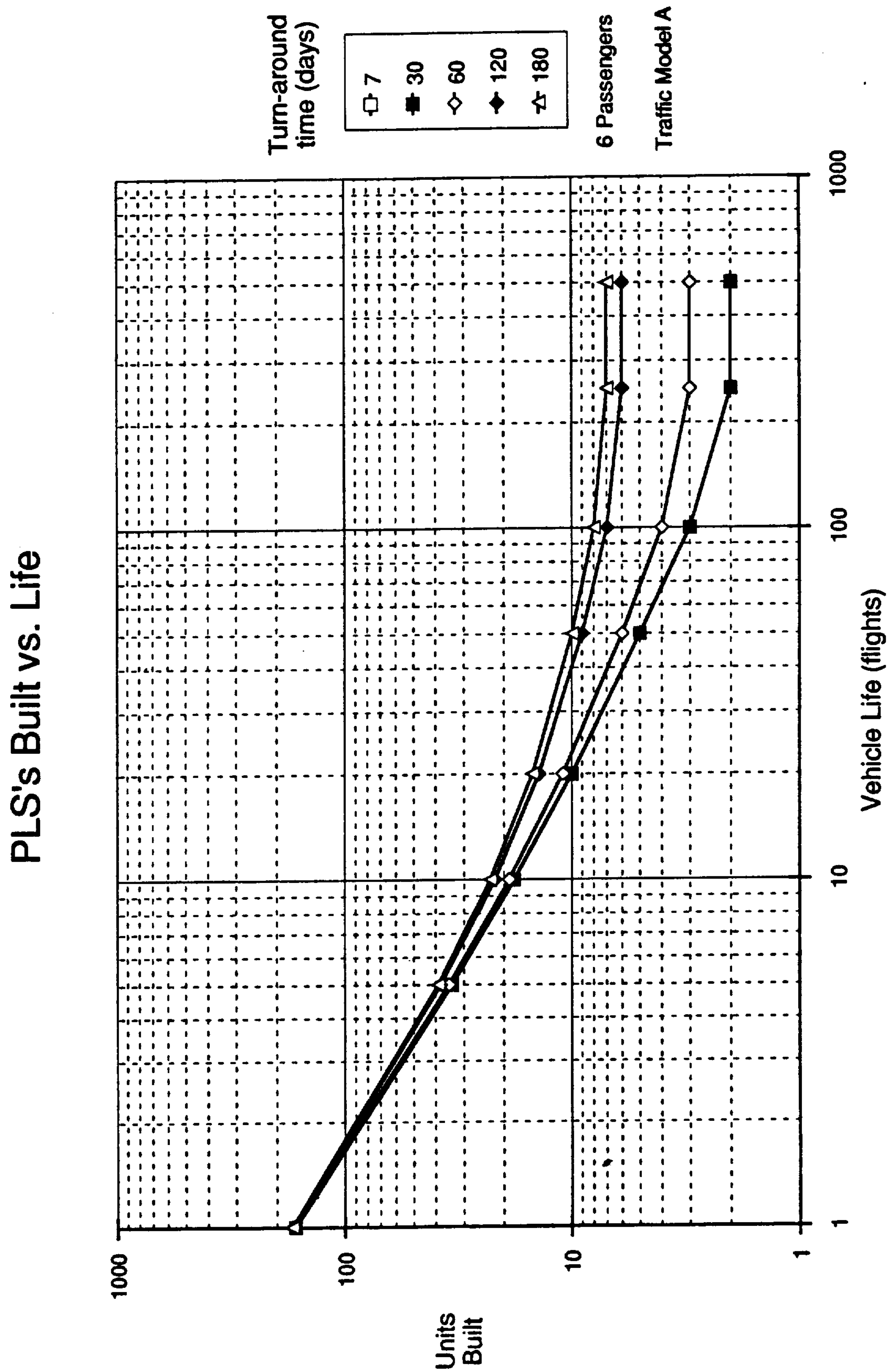
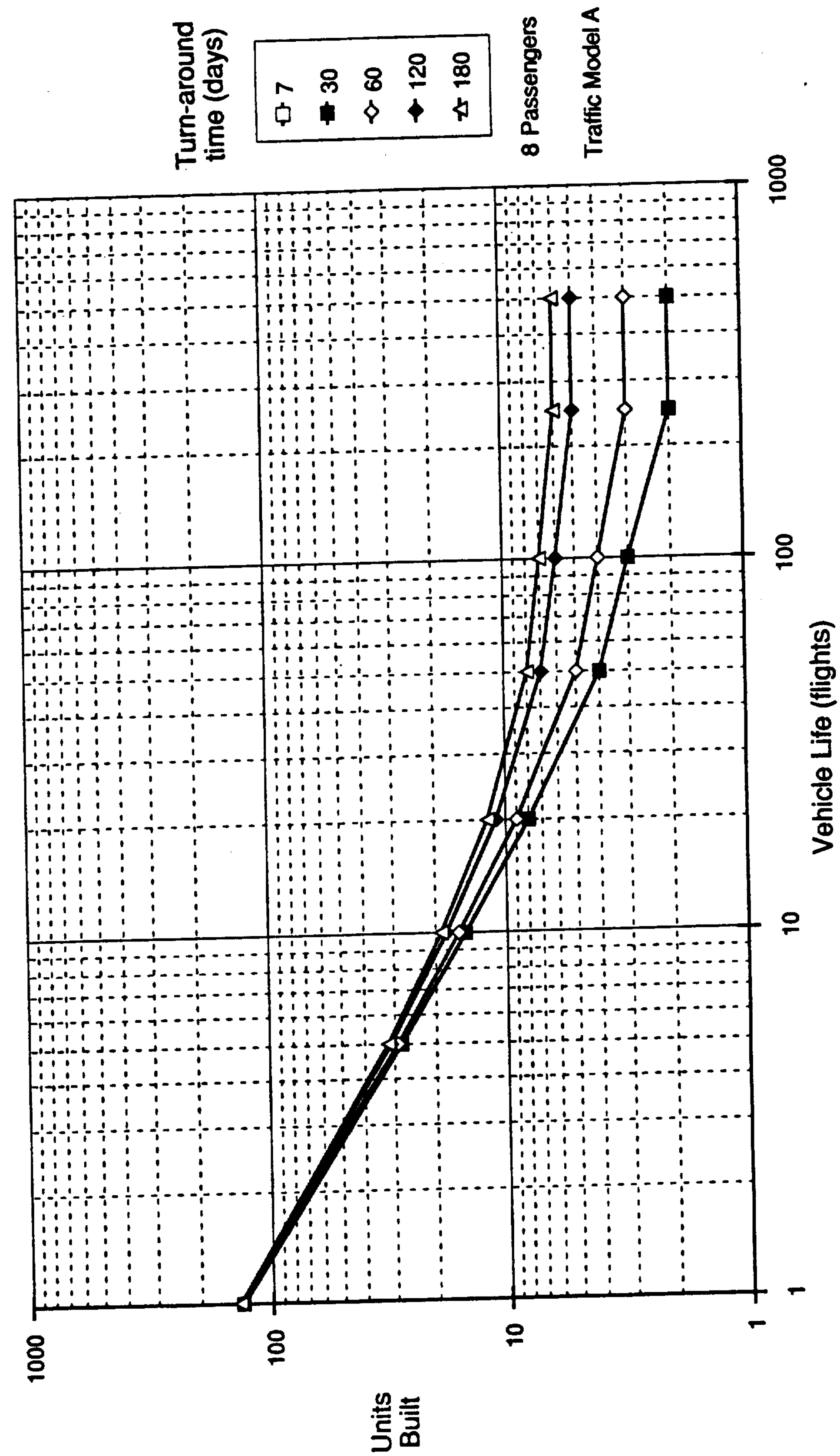
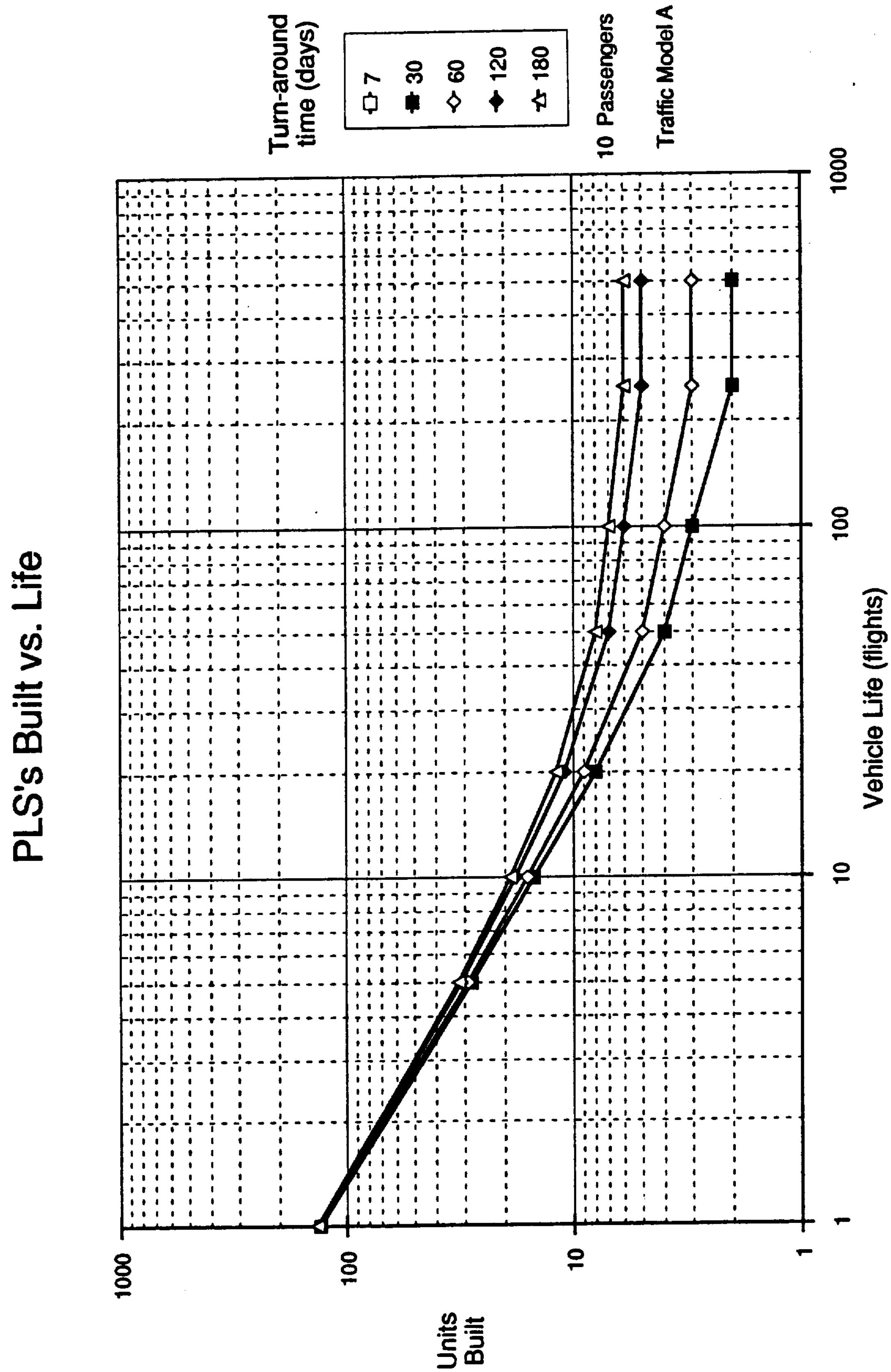
1
2
3
4
5
6
7
Year
1996
2000
2004
2008
2012
2016
2020


PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
4 Passengers
Traffic Model A
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

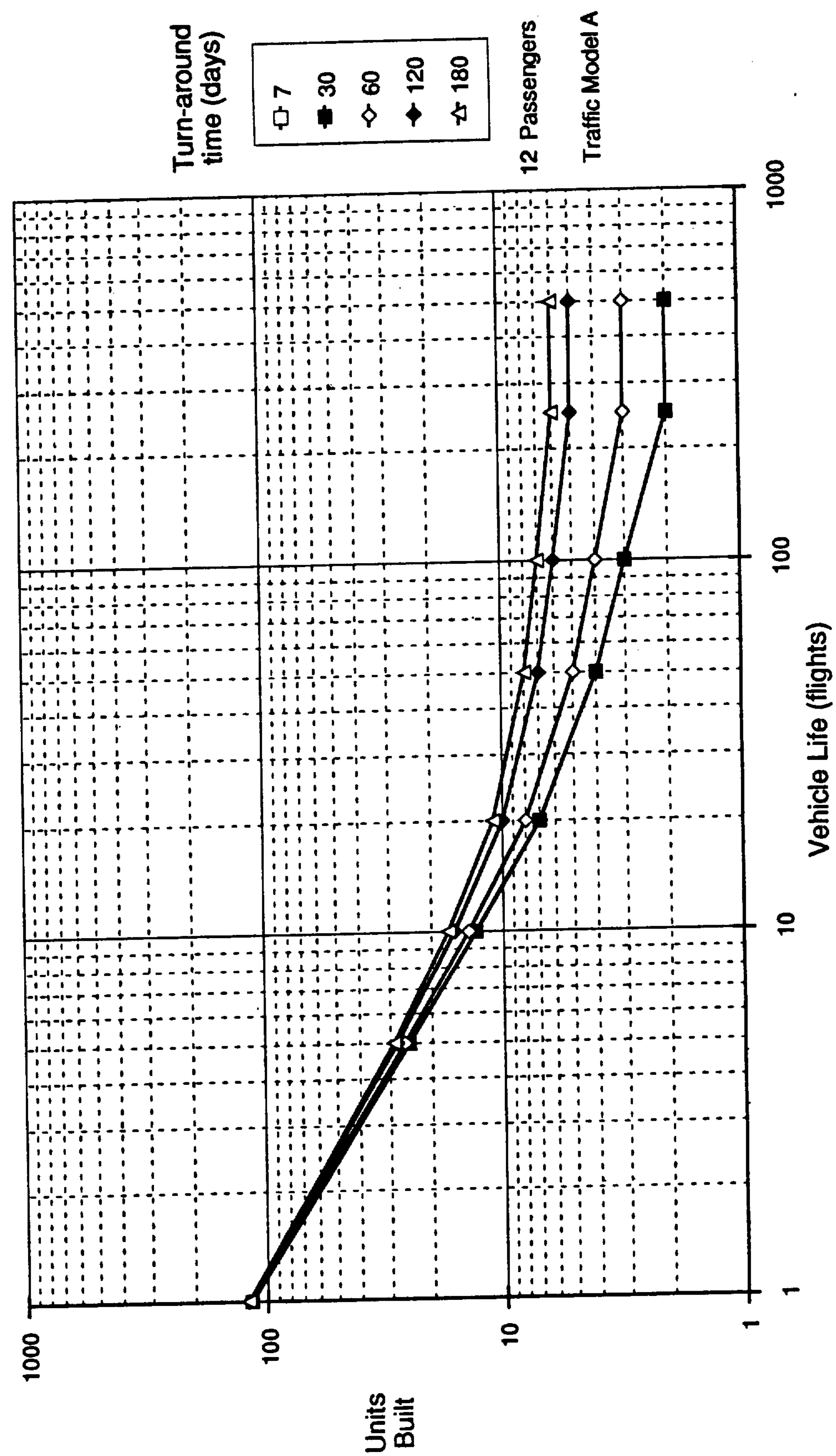

PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
6 Passengers
Traffic Model A
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

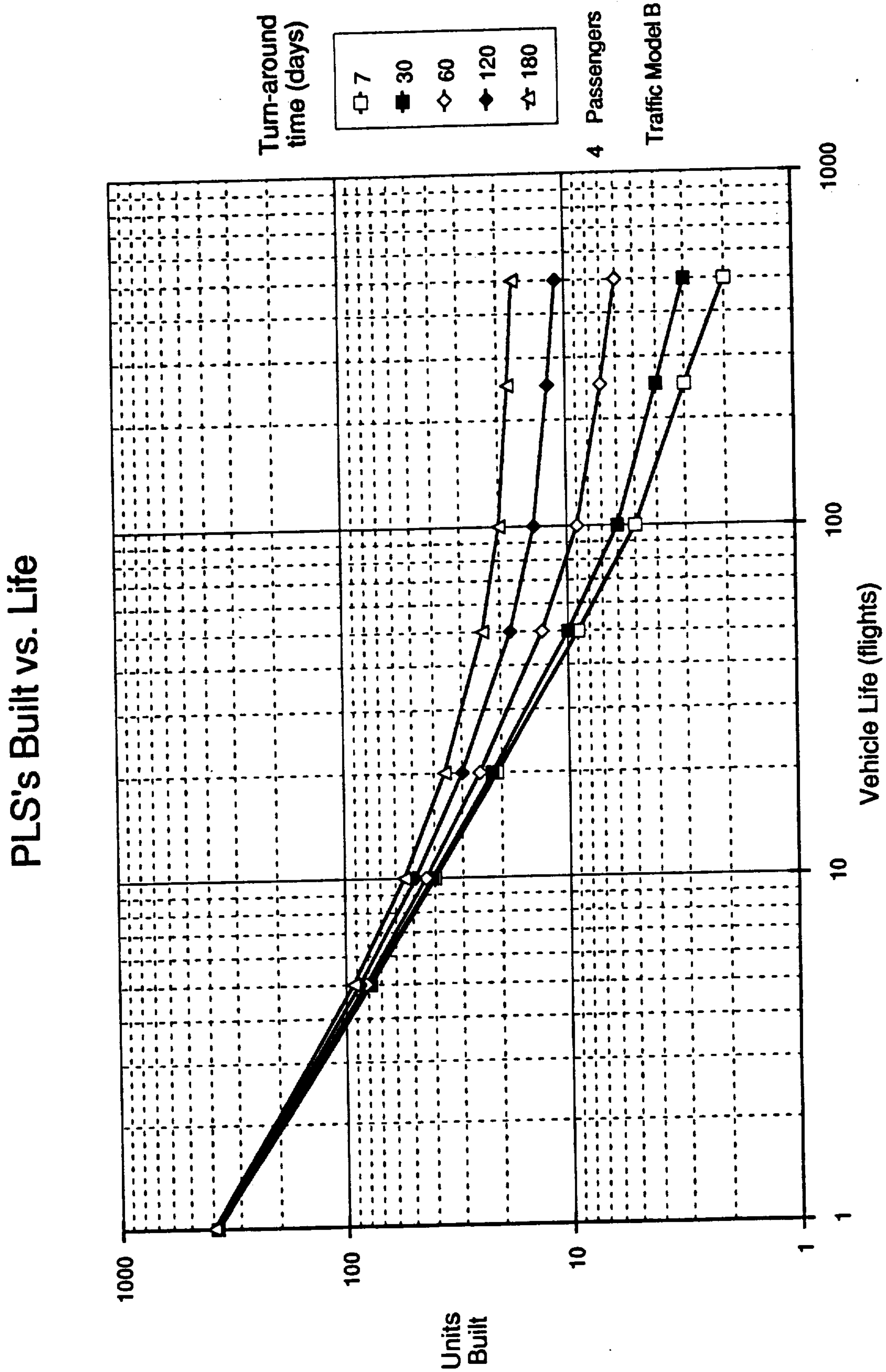
PLS's Built vs. Life



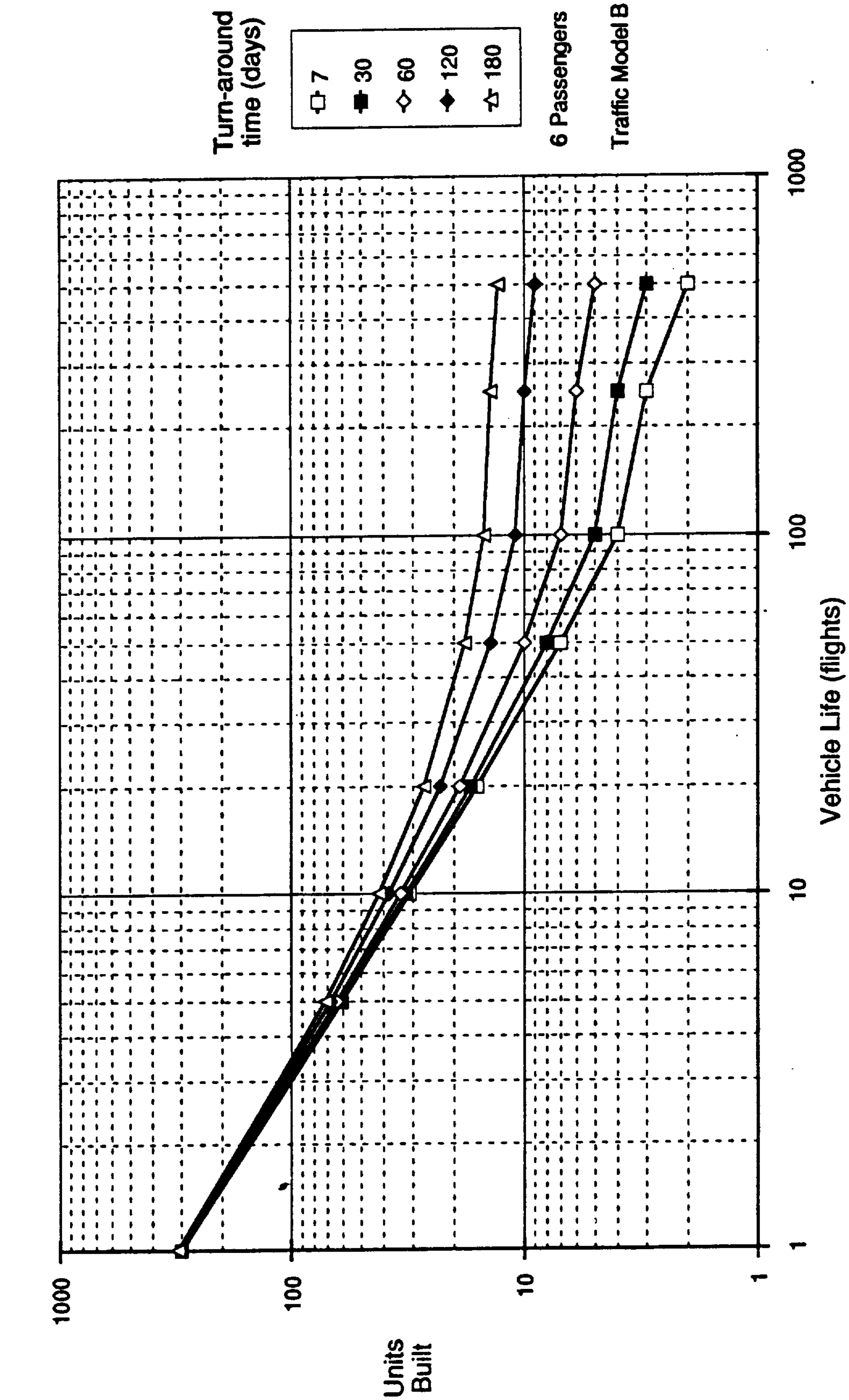

PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
10 Passengers
Traffic Model A
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

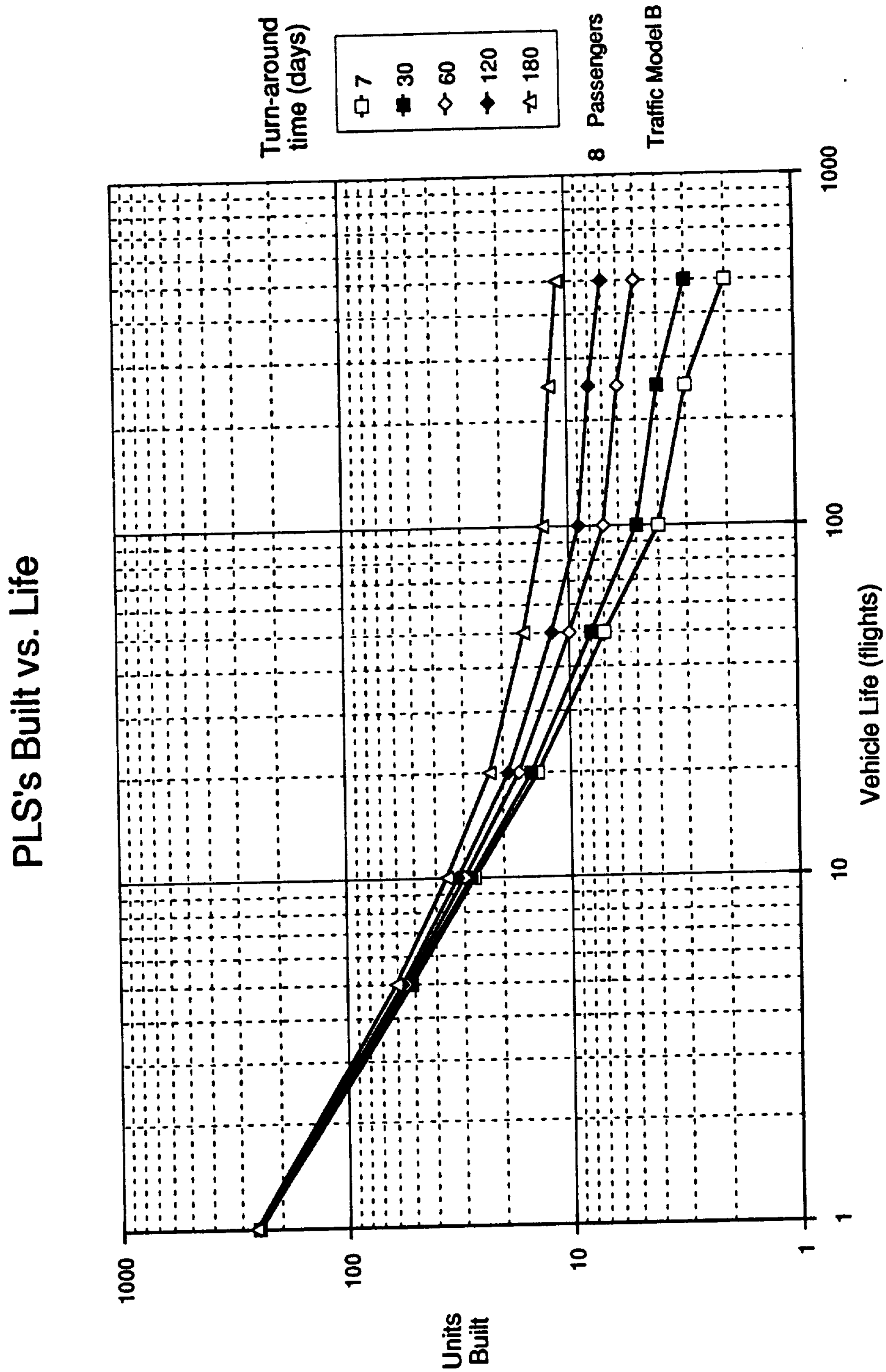
PLS's Built vs. Life




PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
4 Passengers
Traffic Model B
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

PLS's Built vs. Life




PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
8 Passengers
Traffic Model B
Units Built
1000
100
10
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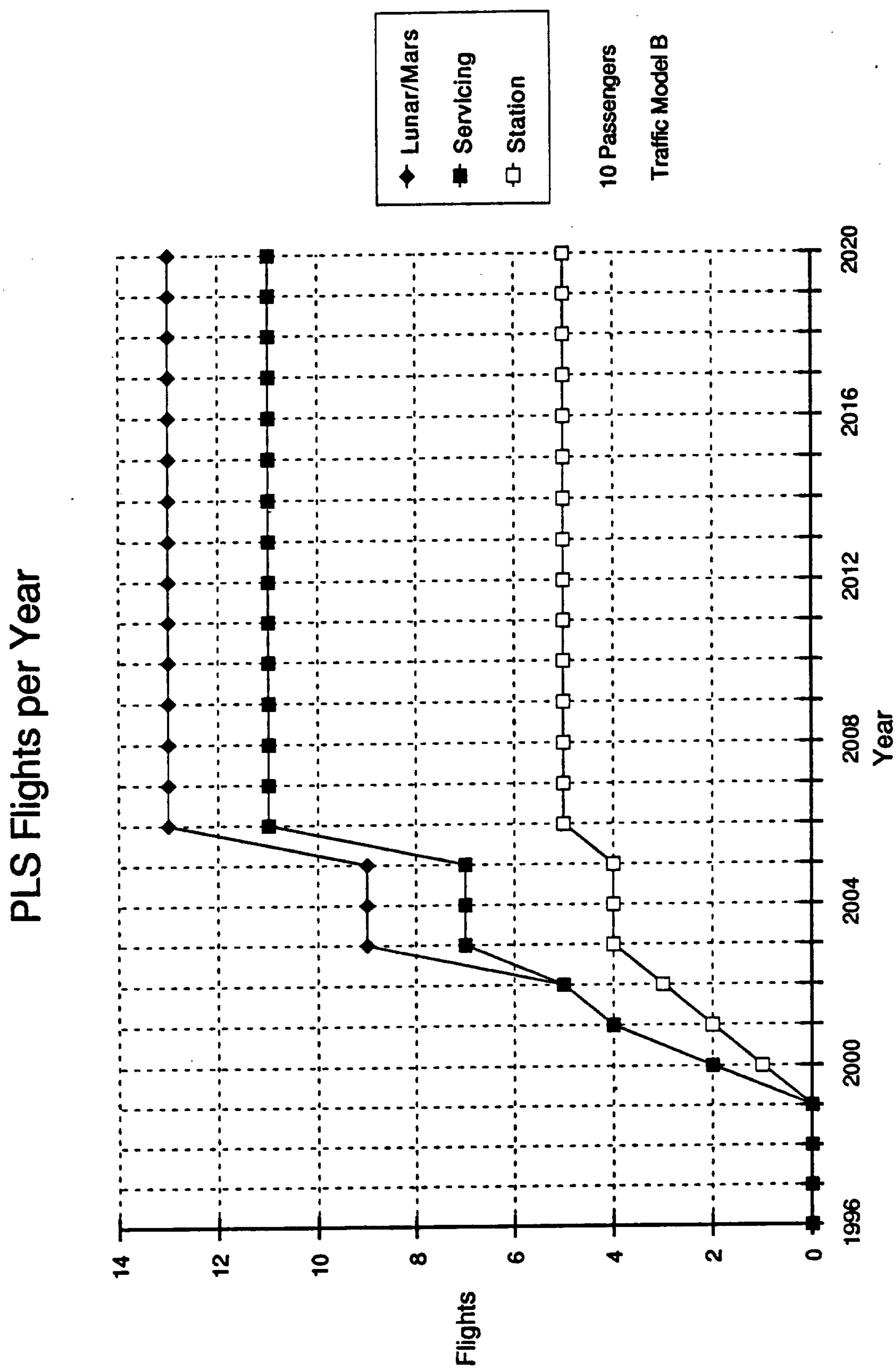
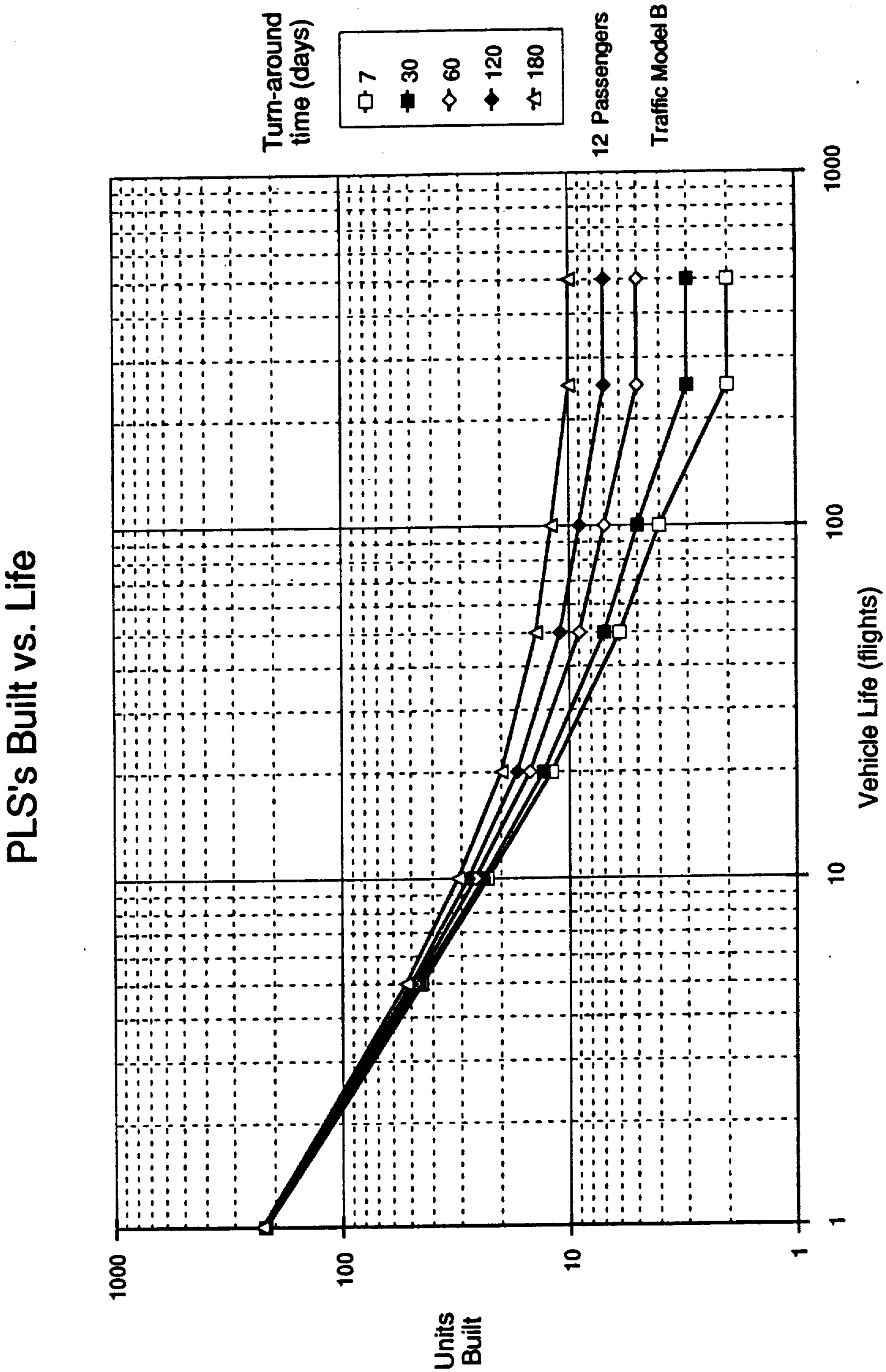
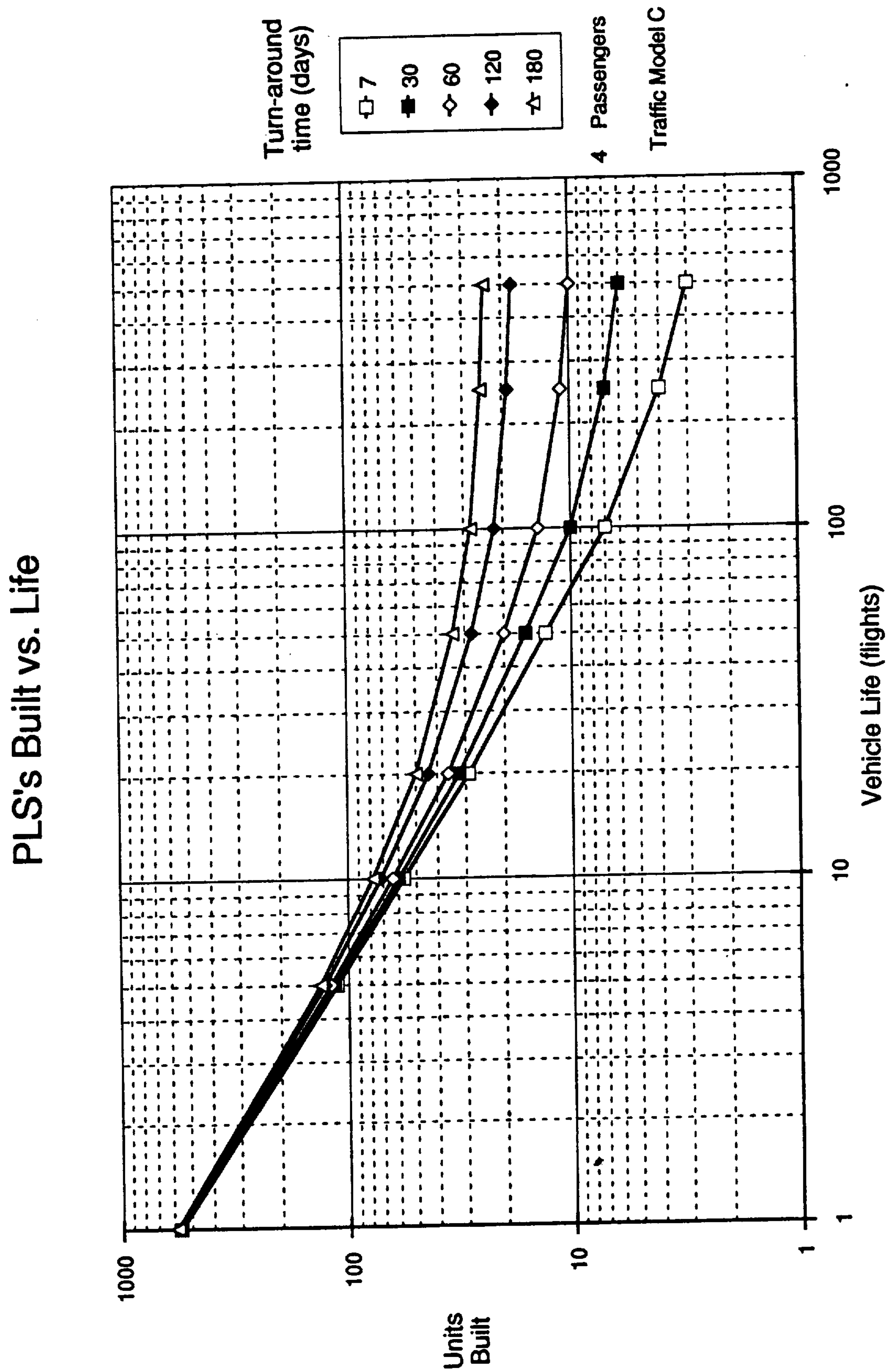
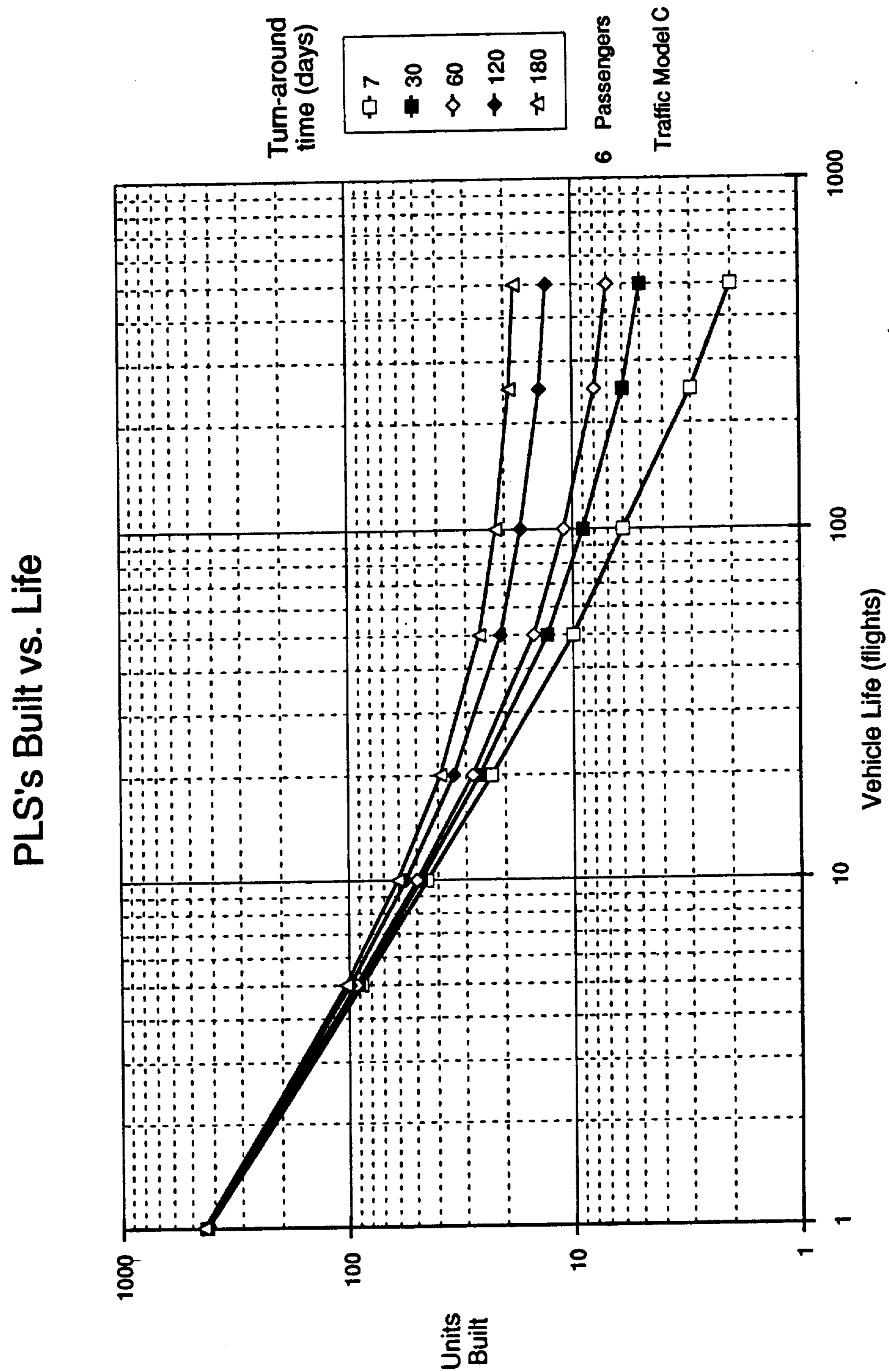
Vehicle Life (flights)
1
10
100
1000


PLS Flights per Year
Lunar/Mars
Servicing
Station
10 Passengers
Traffic Model B
Flights
14
12
10
8
6
4
2
0
1996
2000
2004
2008
2012
2016
2020
Year


PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
12 Passengers
Traffic Model B
Units Built
1000
100
10
1
Vehicle Life (flights)


PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
4 Passengers
Traffic Model C
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000


PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
6 Passengers
Traffic Model C
Units Built
1000
100
10
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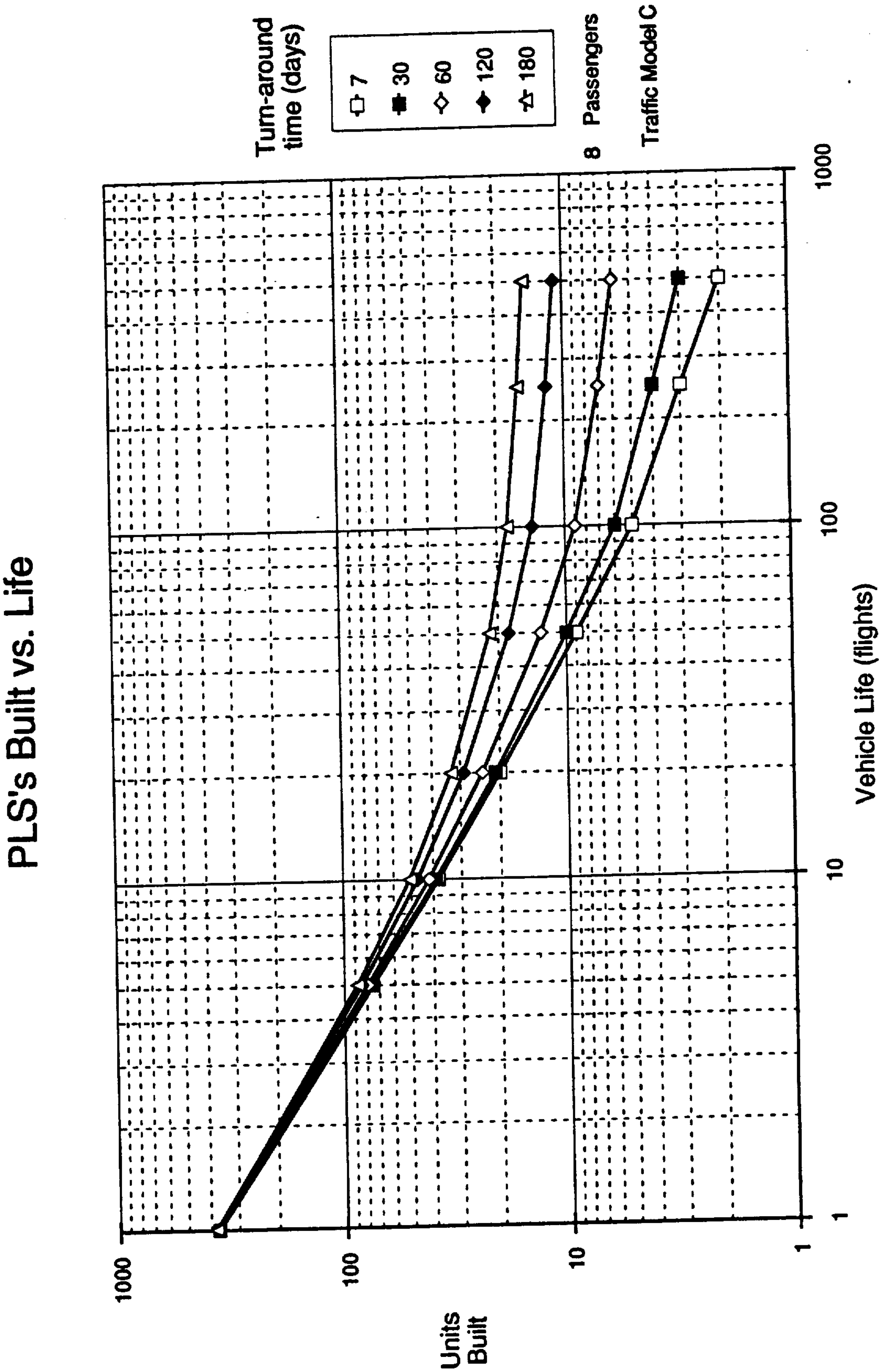
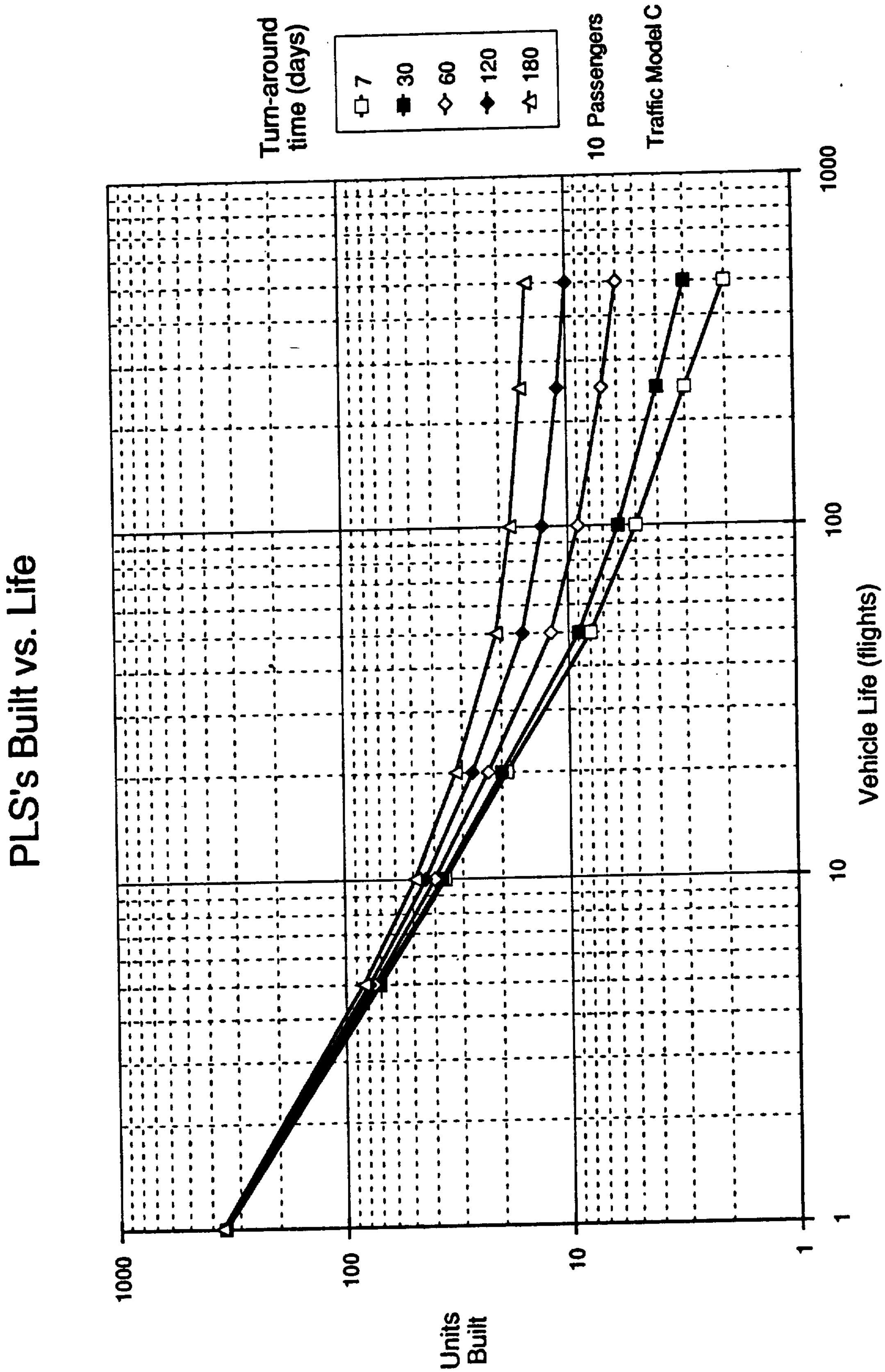
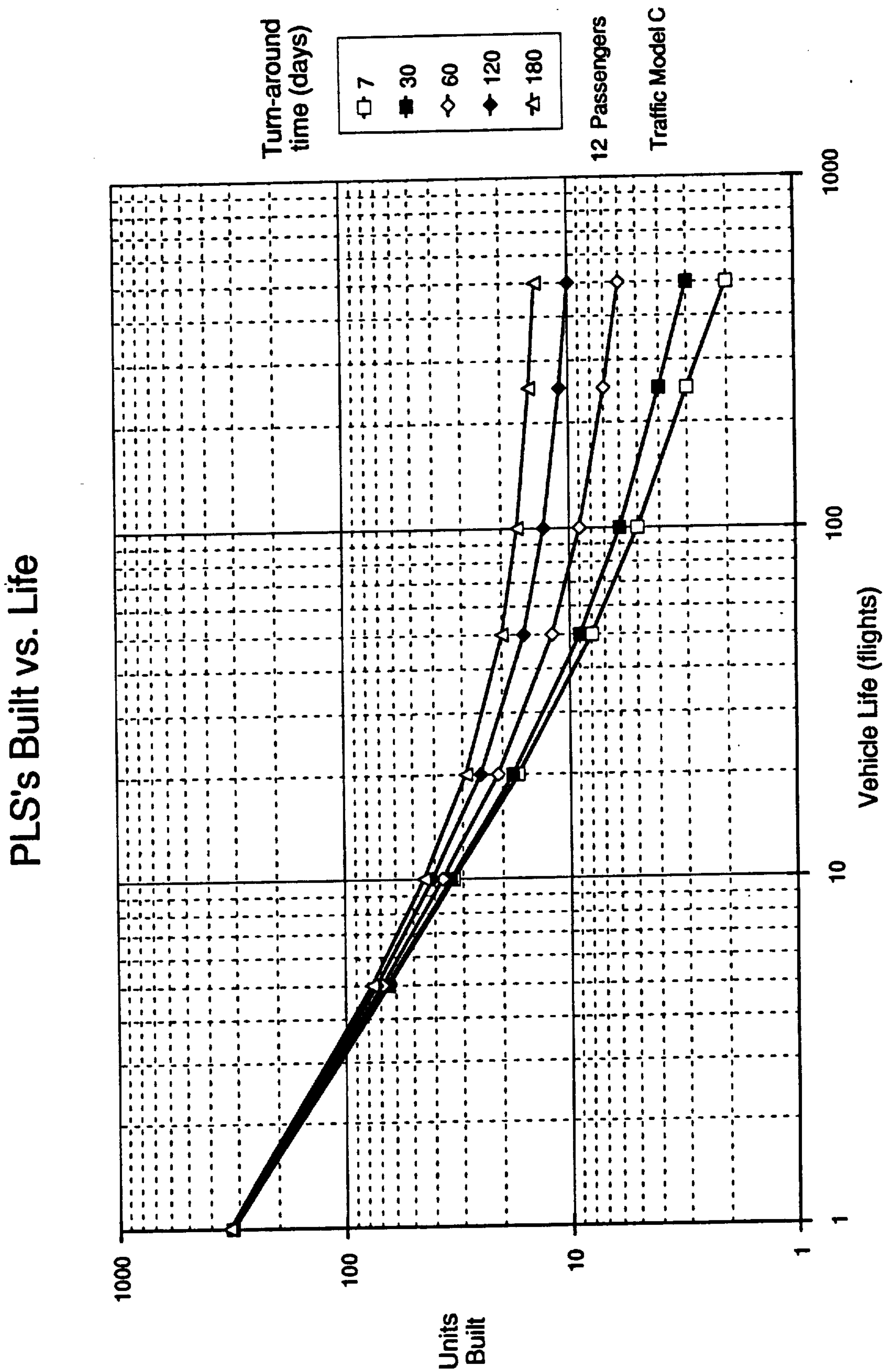
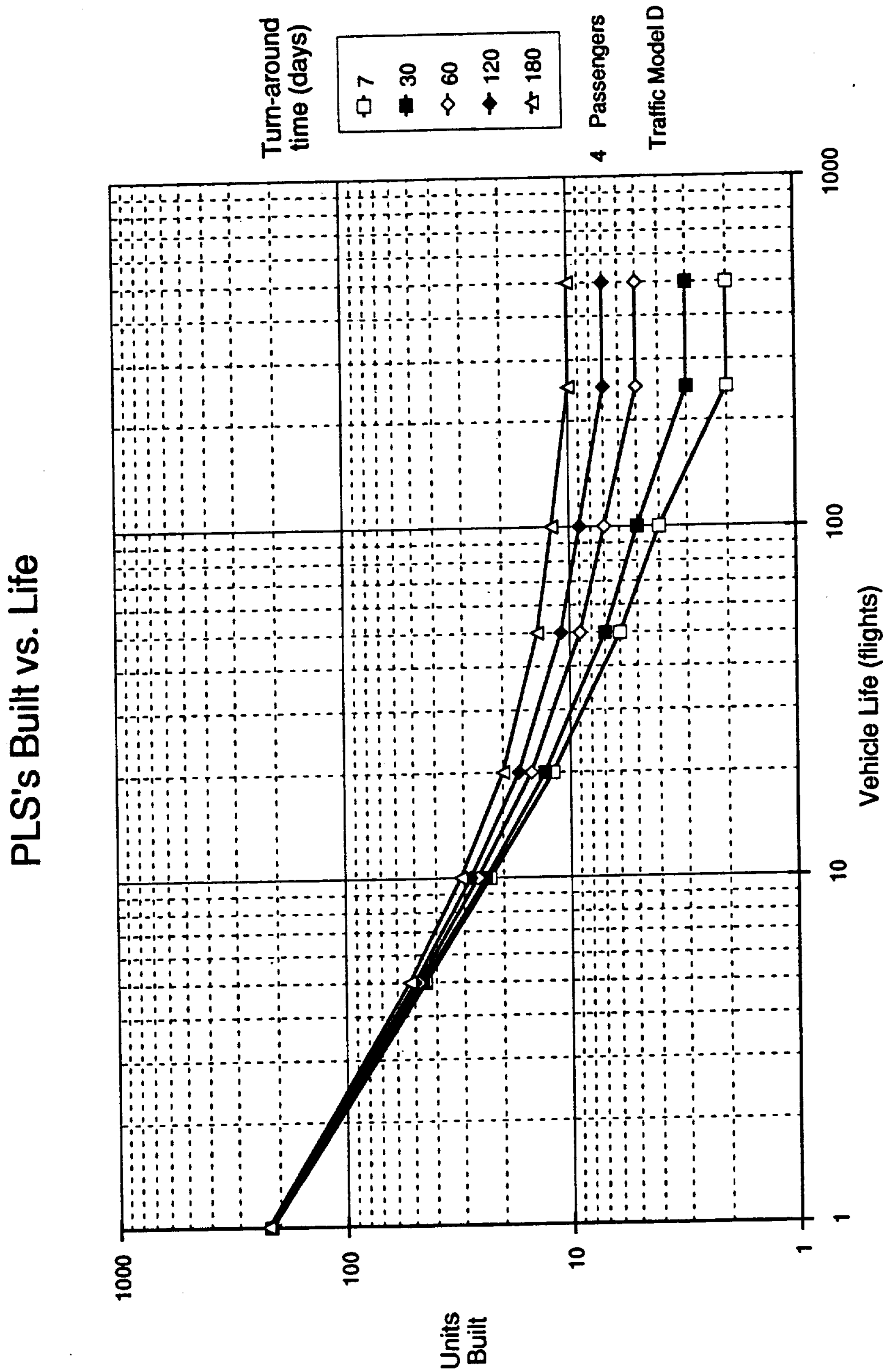
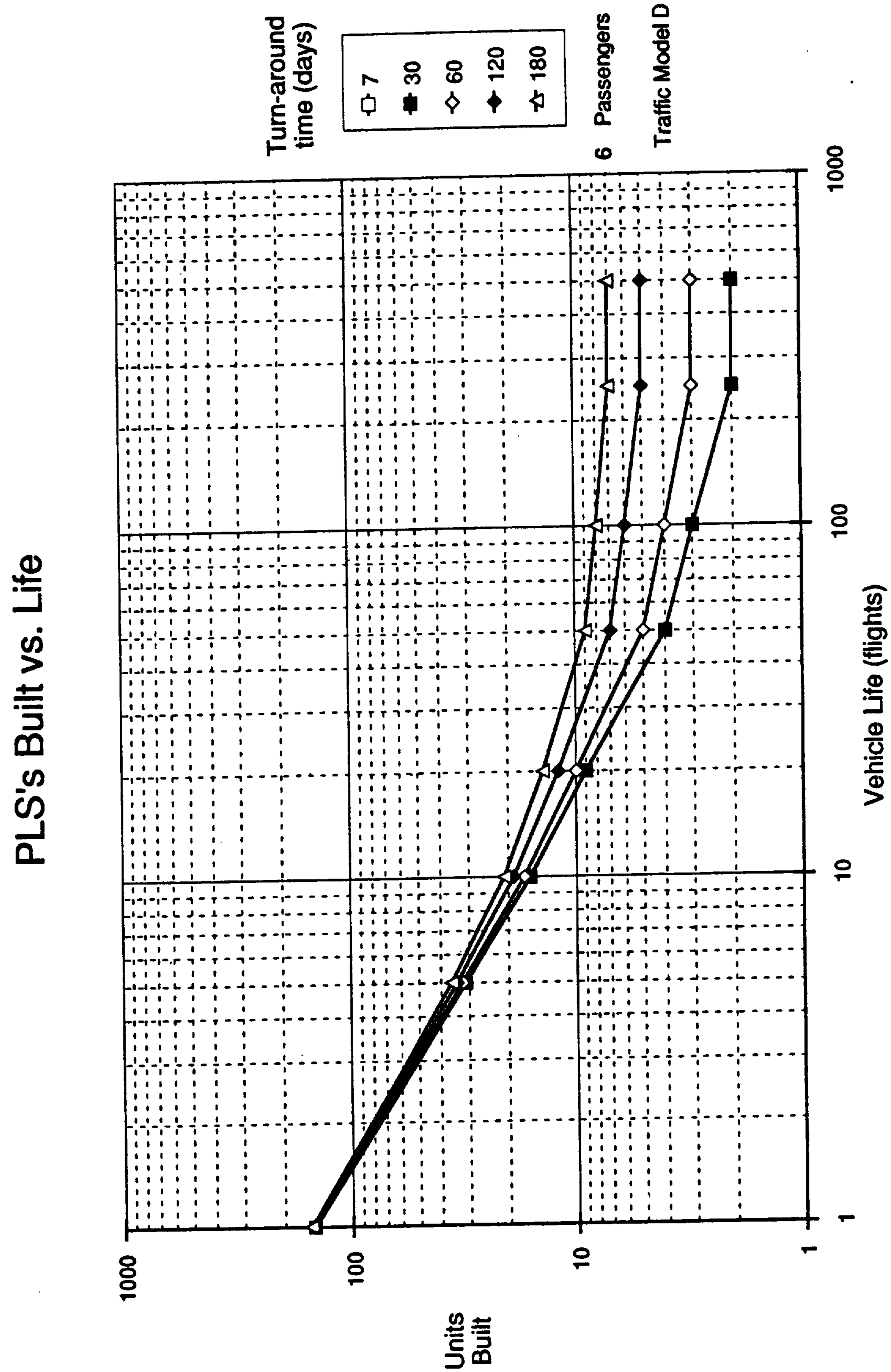
Vehicle Life (flights)
1
10
100
1000

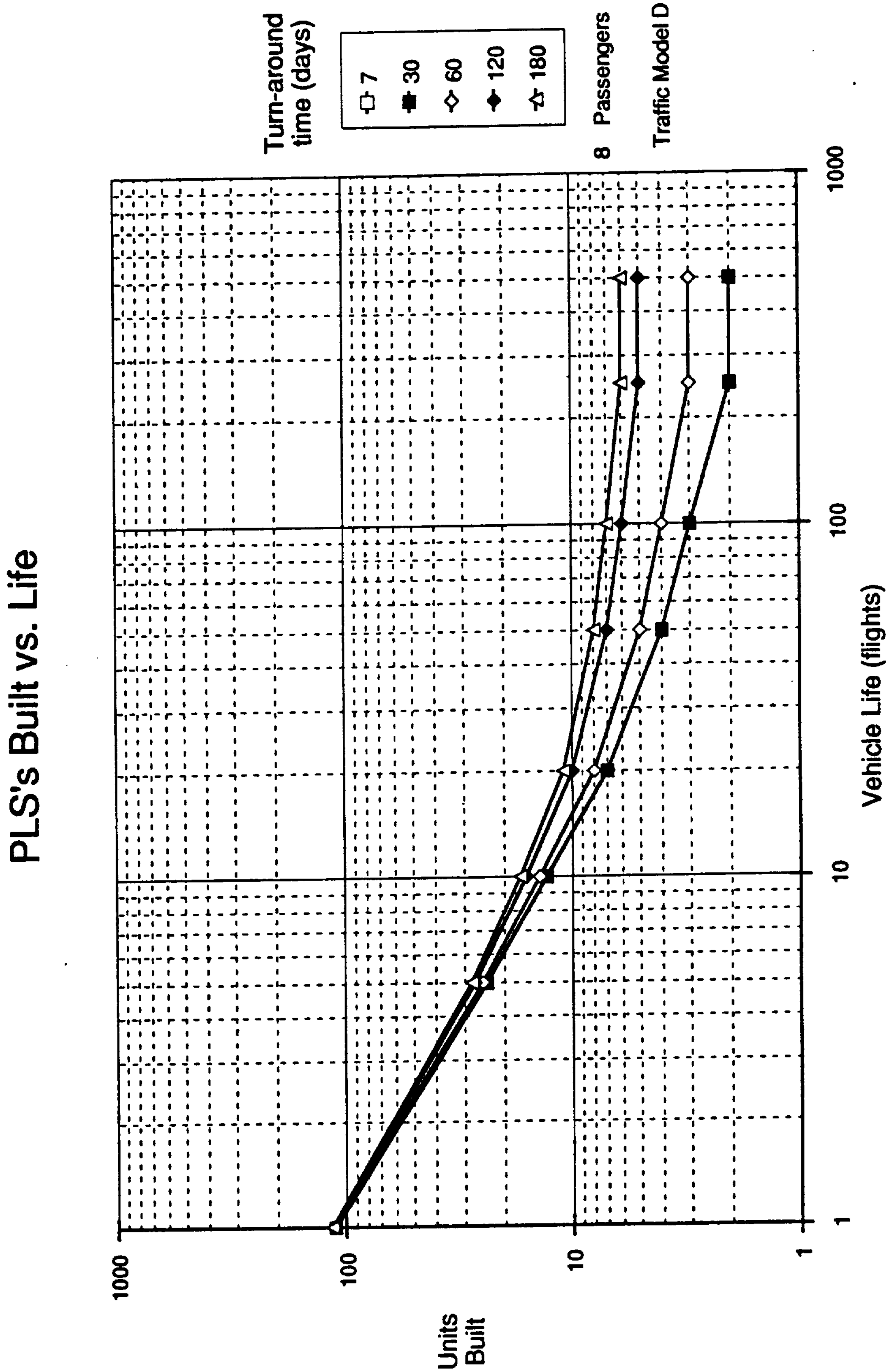

PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
8 Passengers
Traffic Model C
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

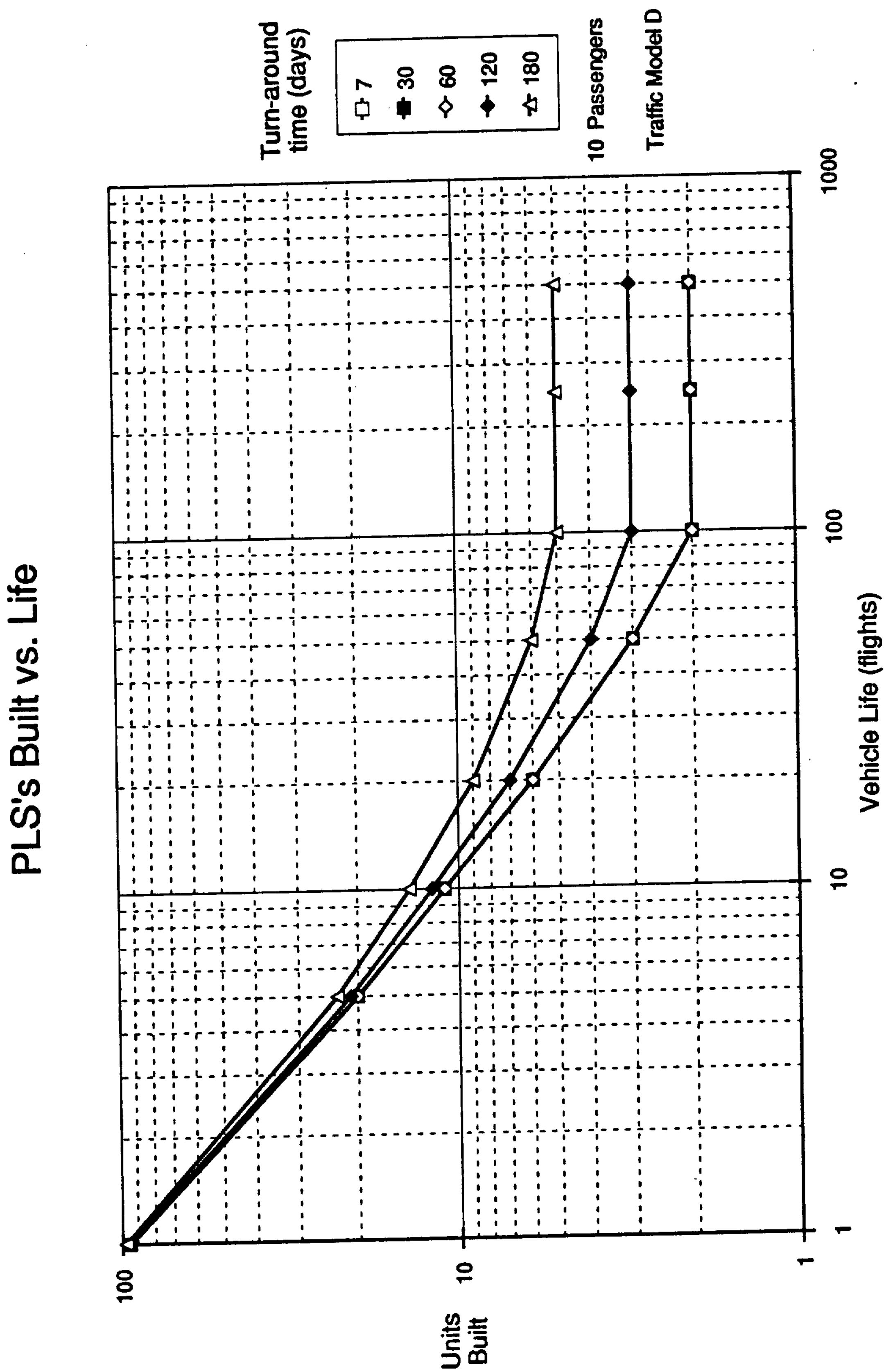

PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
10 Passengers
Traffic Model C
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

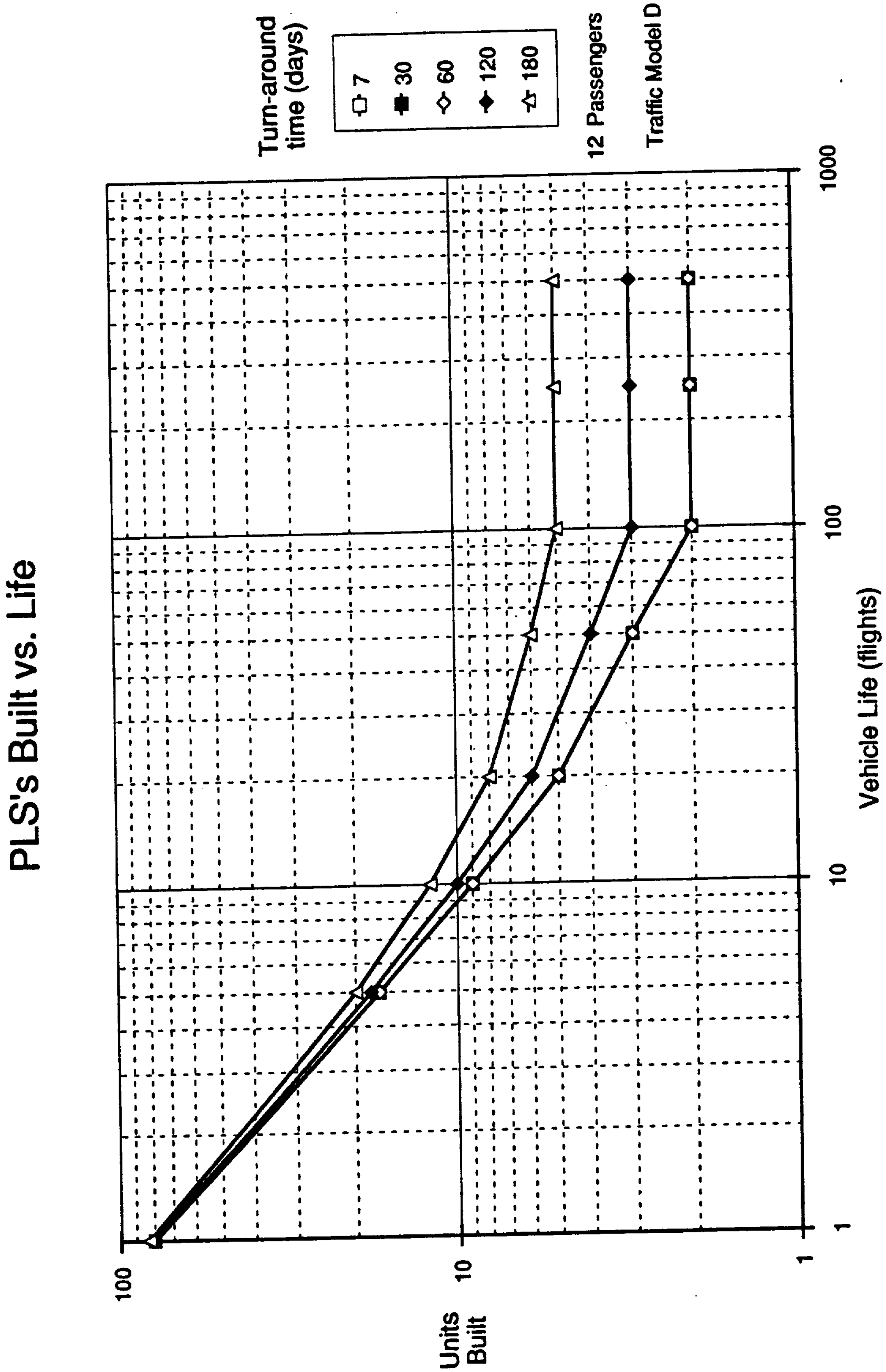

PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
12 Passengers
Traffic Model C
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

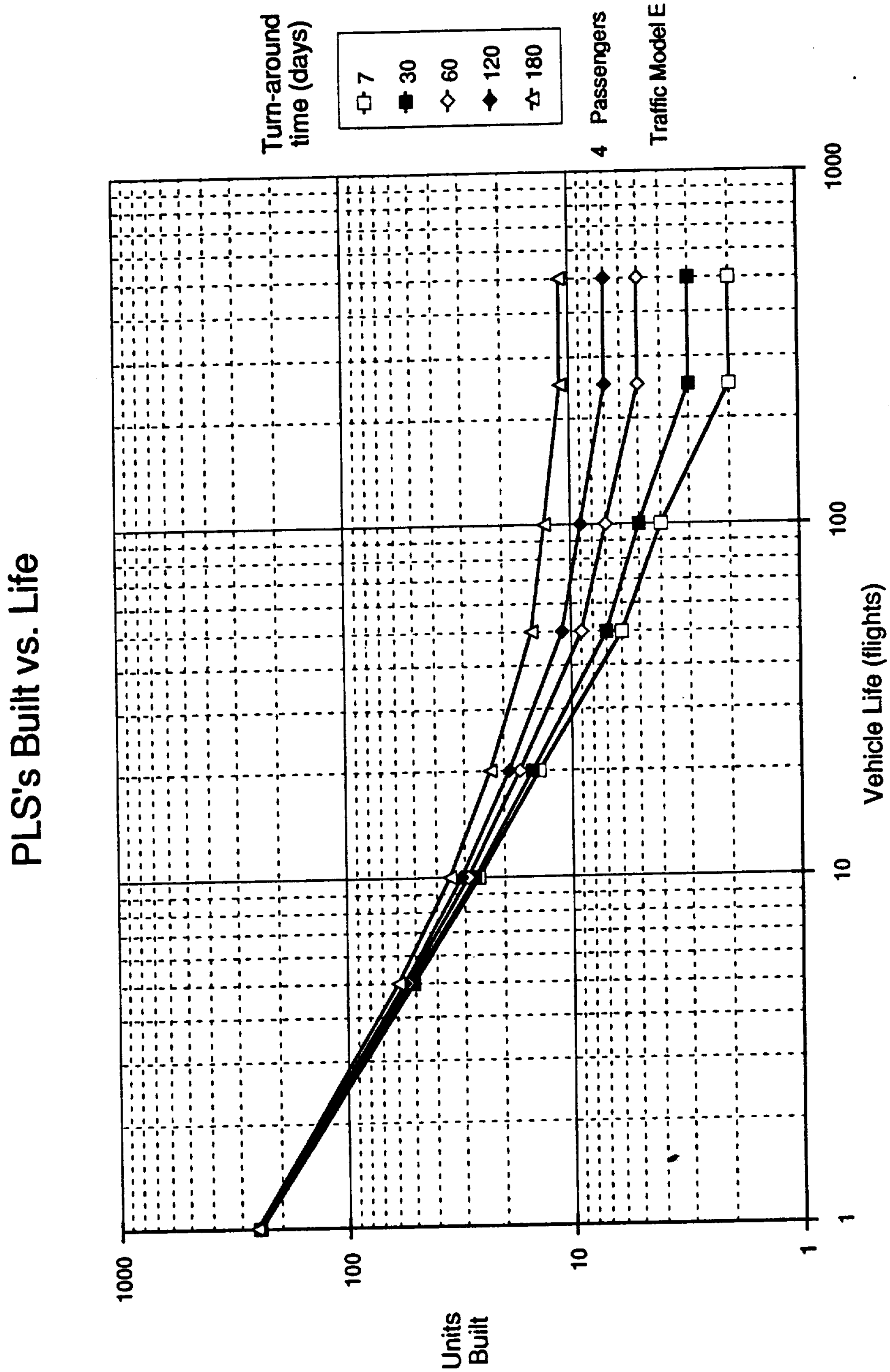

PLS's Built vs. Life
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000
Turn-around time (days)
7
30
60
120
180
4 Passengers
Traffic Model D


PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
6 Passengers
Traffic Model D
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

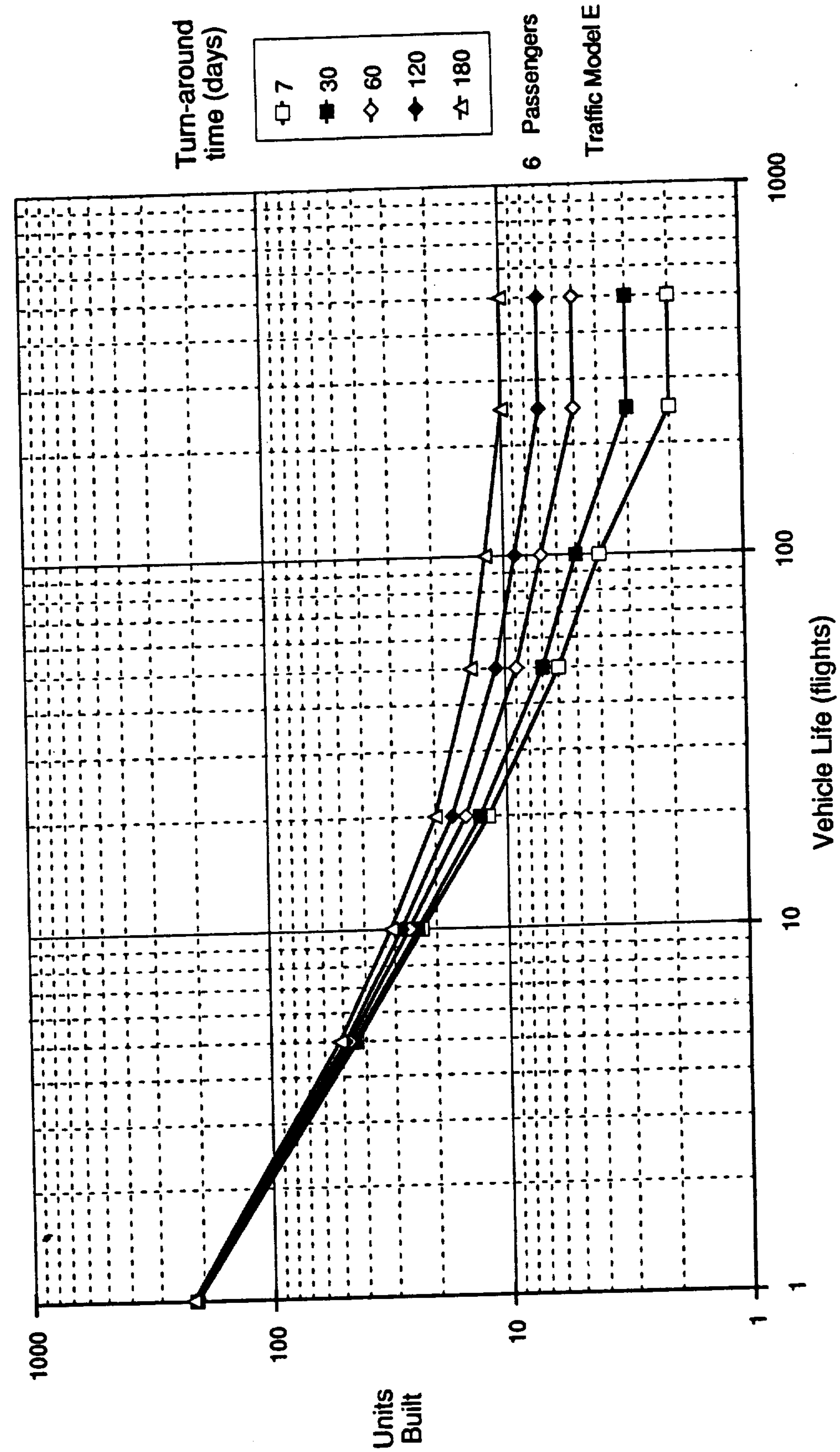

PLS's Built vs. Life
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000
Turn-around time (days)
7
30
60
120
180
8 Passengers
Traffic Model D


PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
10 Passengers
Traffic Model D
Units Built
100
10
1
Vehicle Life (flights)
1
10
100
1000

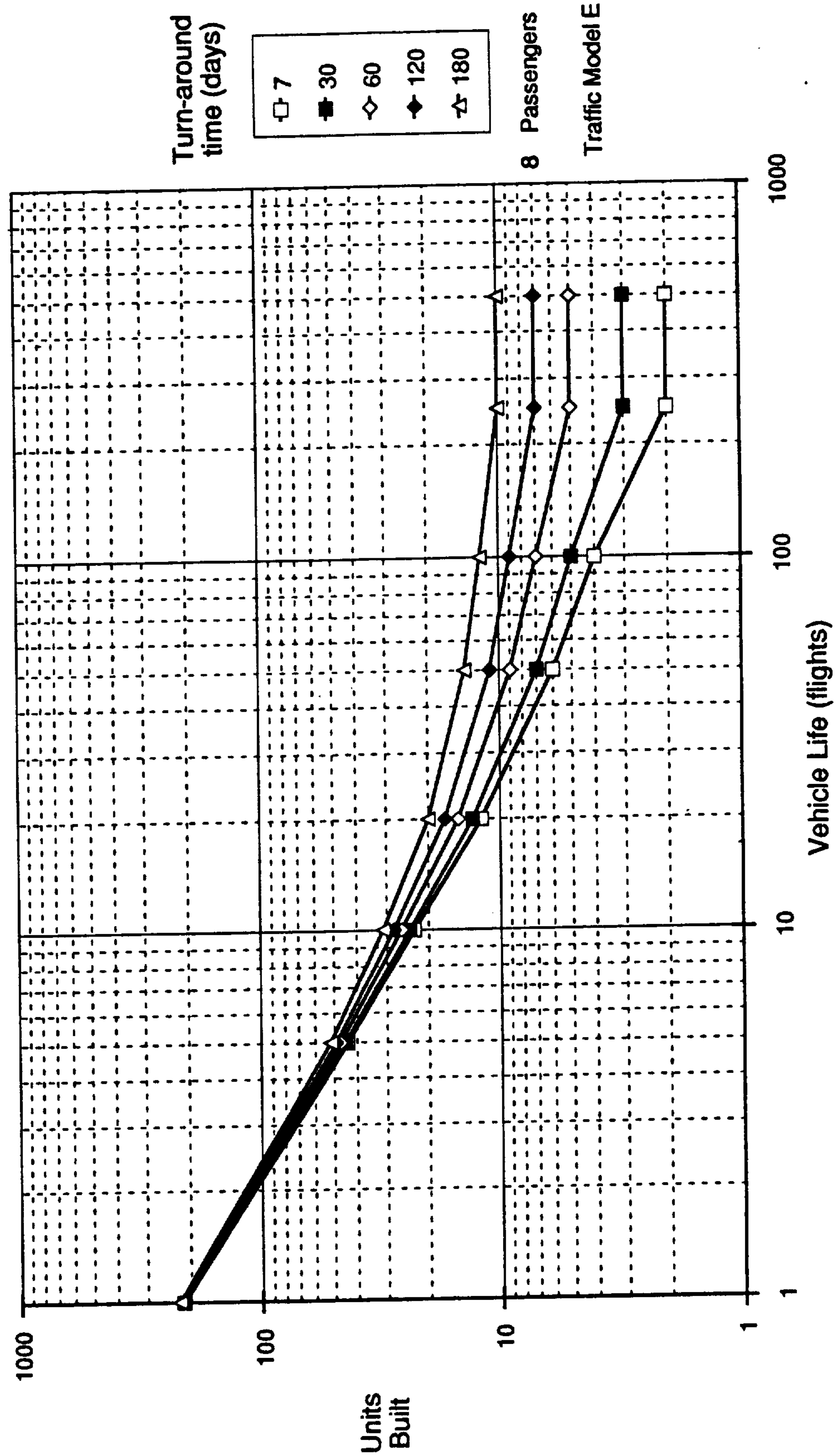

PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
12 Passengers
Traffic Model D
Units Built
100
10
1
Vehicle Life (flights)
1
10
100
1000


PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
4 Passengers
Traffic Model E
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

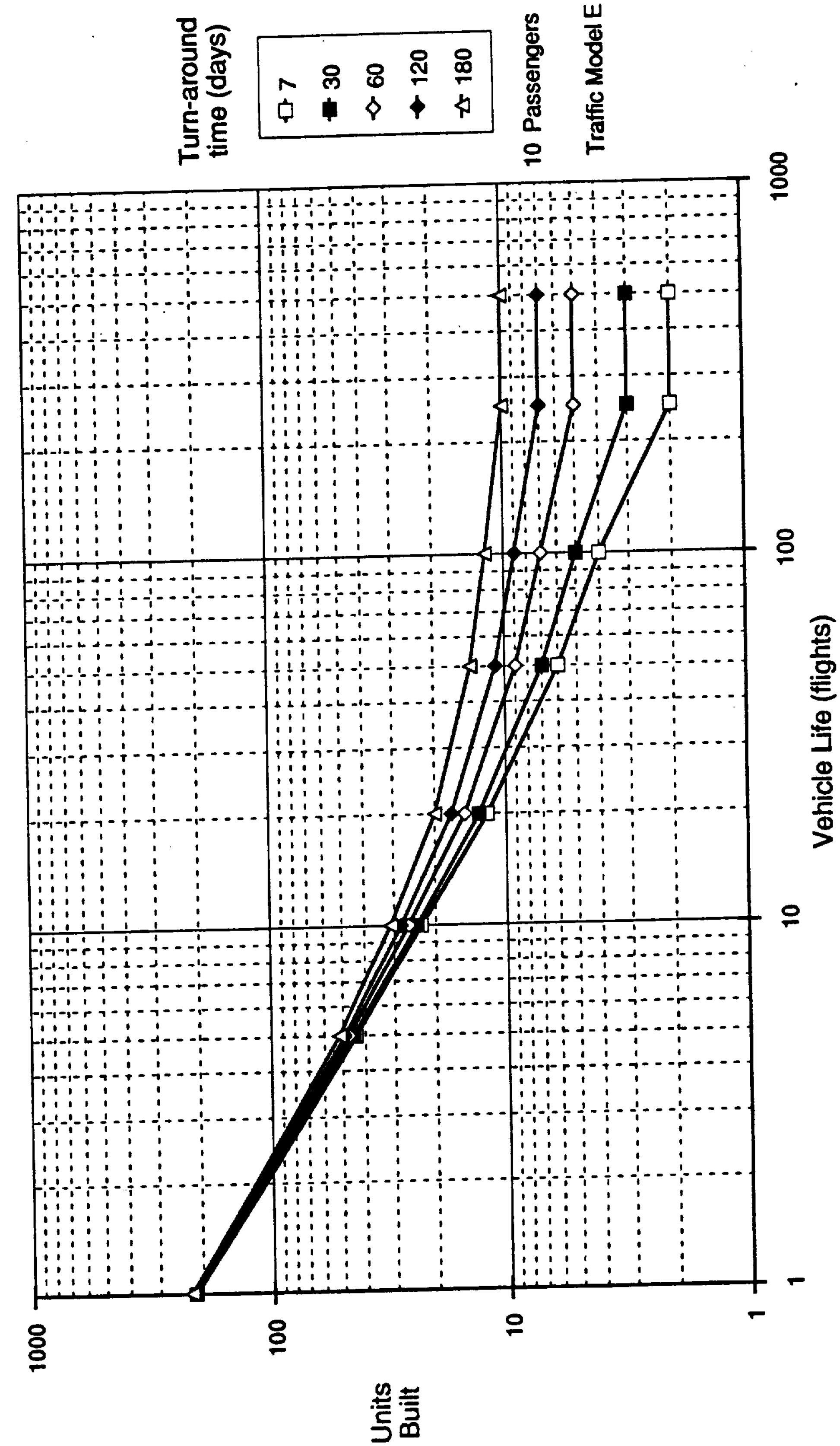
PLS's Built vs. Life

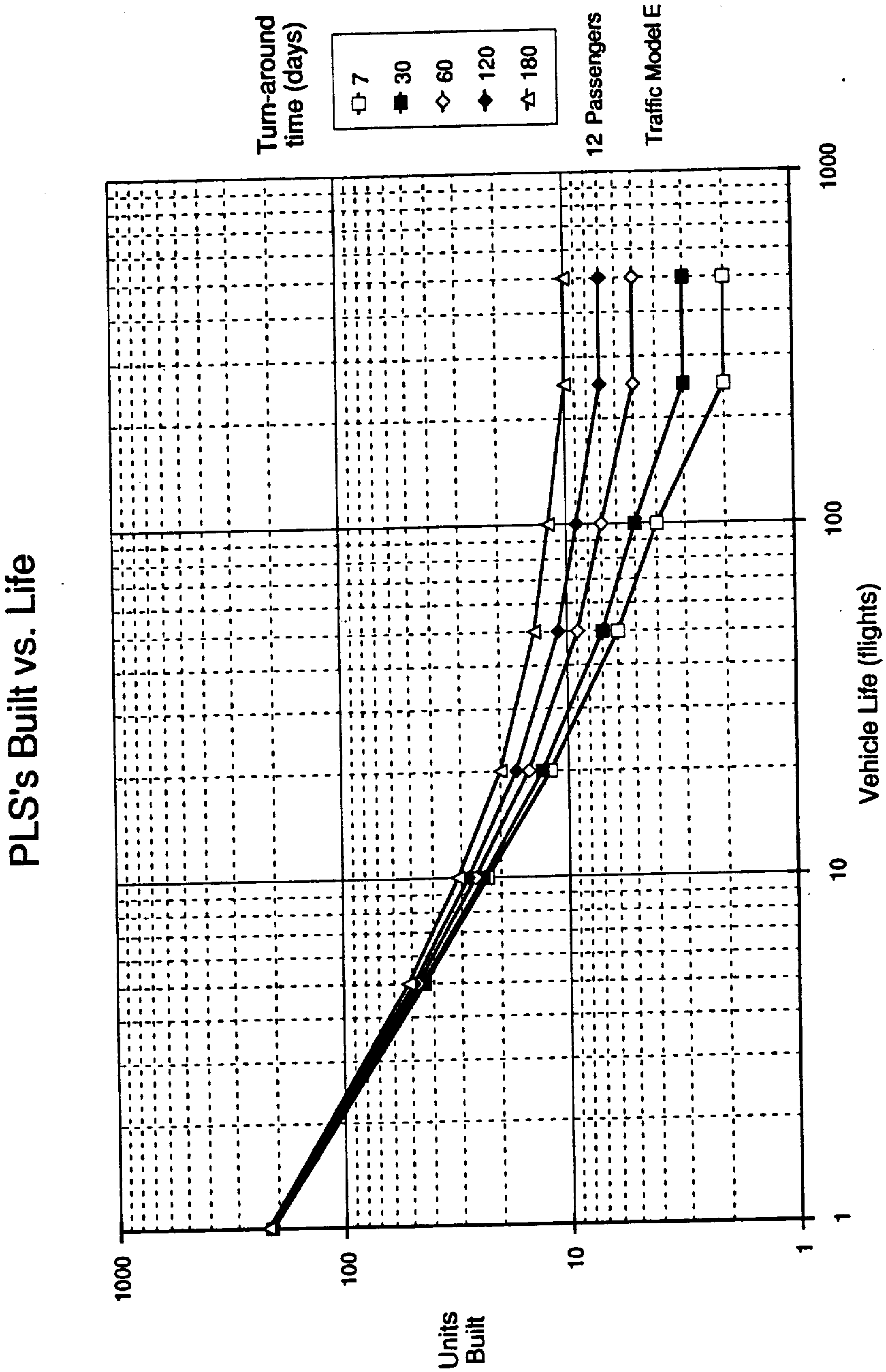


PLS's Built vs. Life

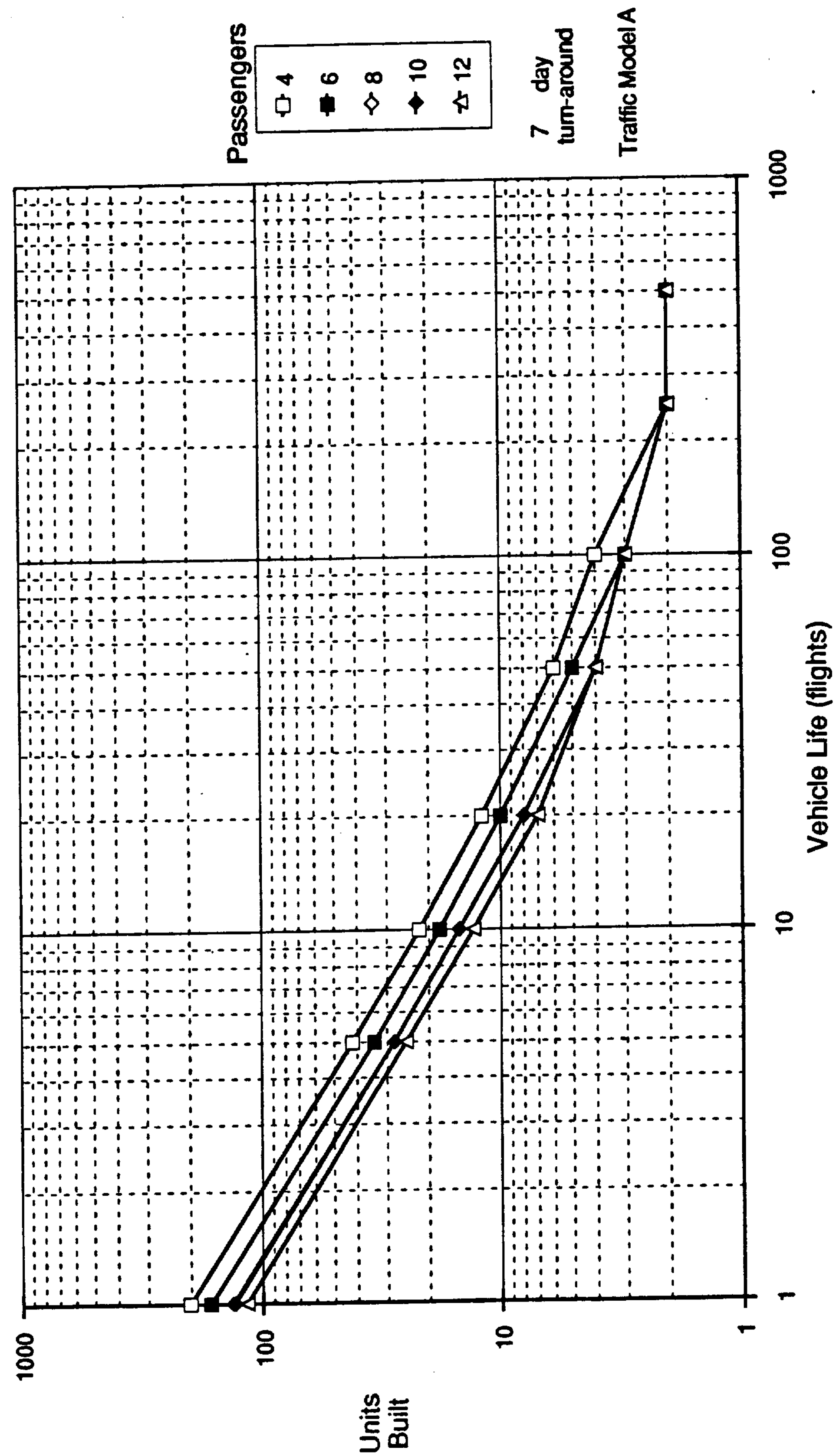


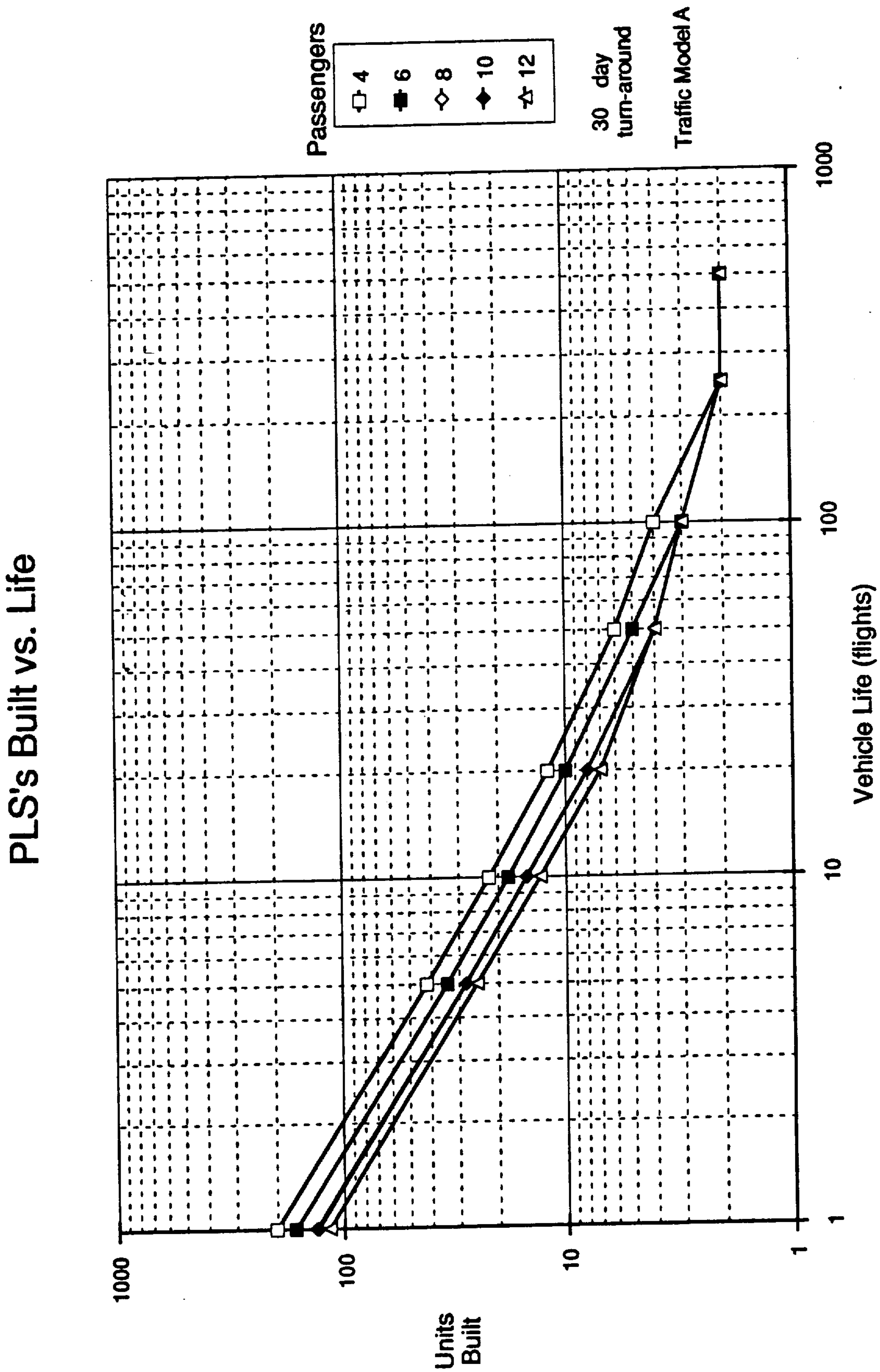
PLS's Built vs. Life

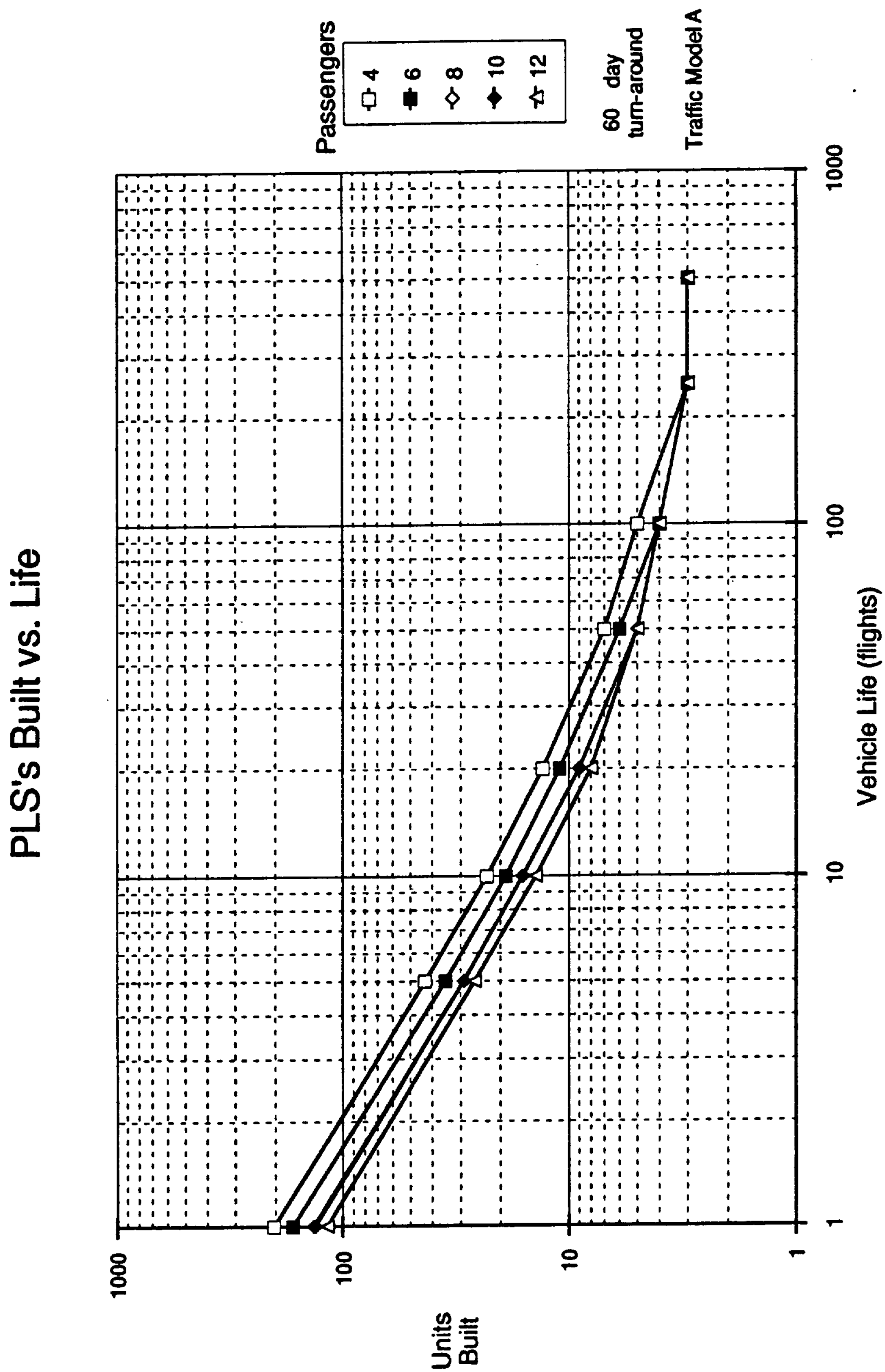



PLS's Built vs. Life
Turn-around time (days)
7
30
60
120
180
12 Passengers
Traffic Model E
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

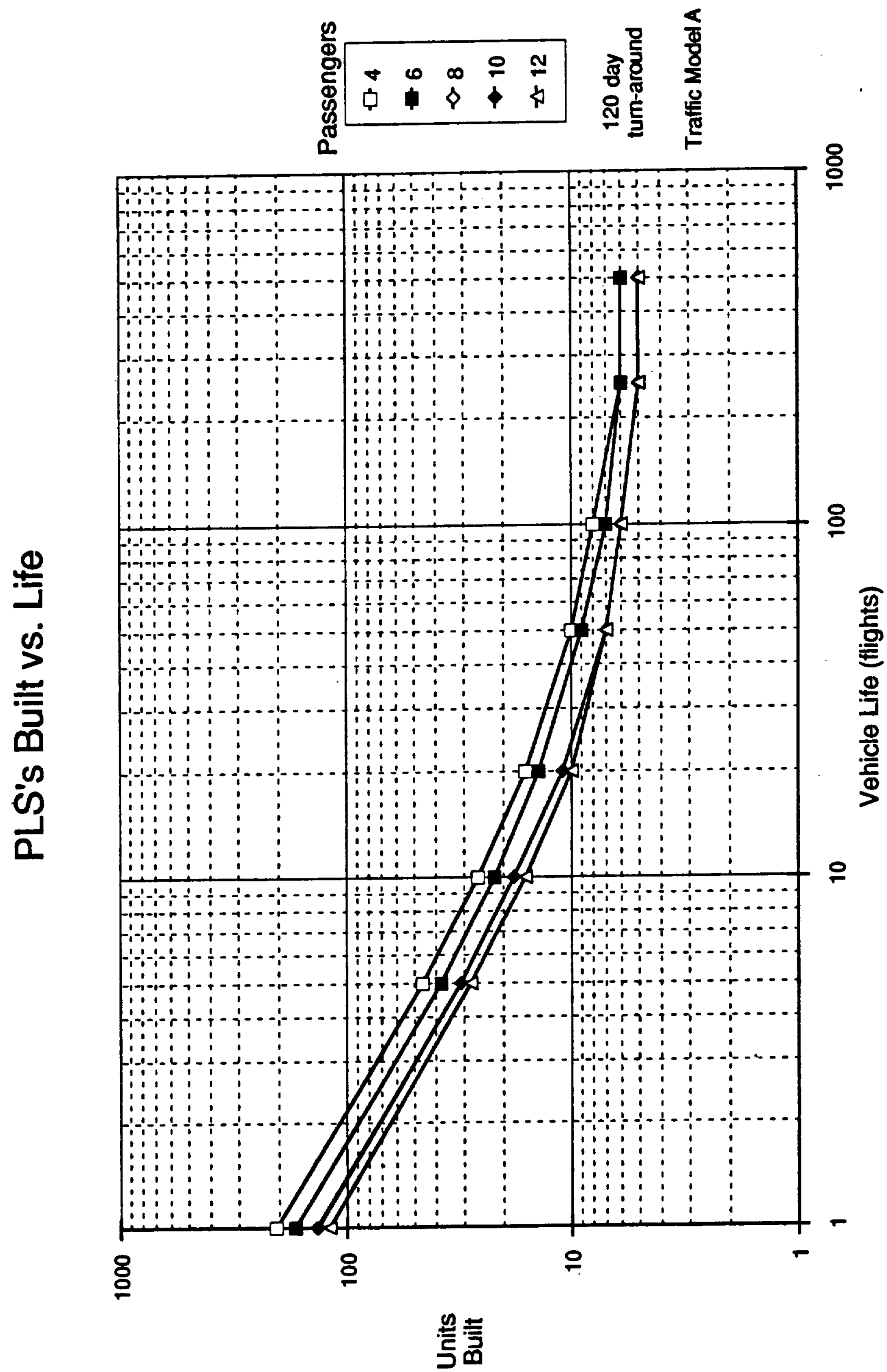
PLS's Built vs. Life



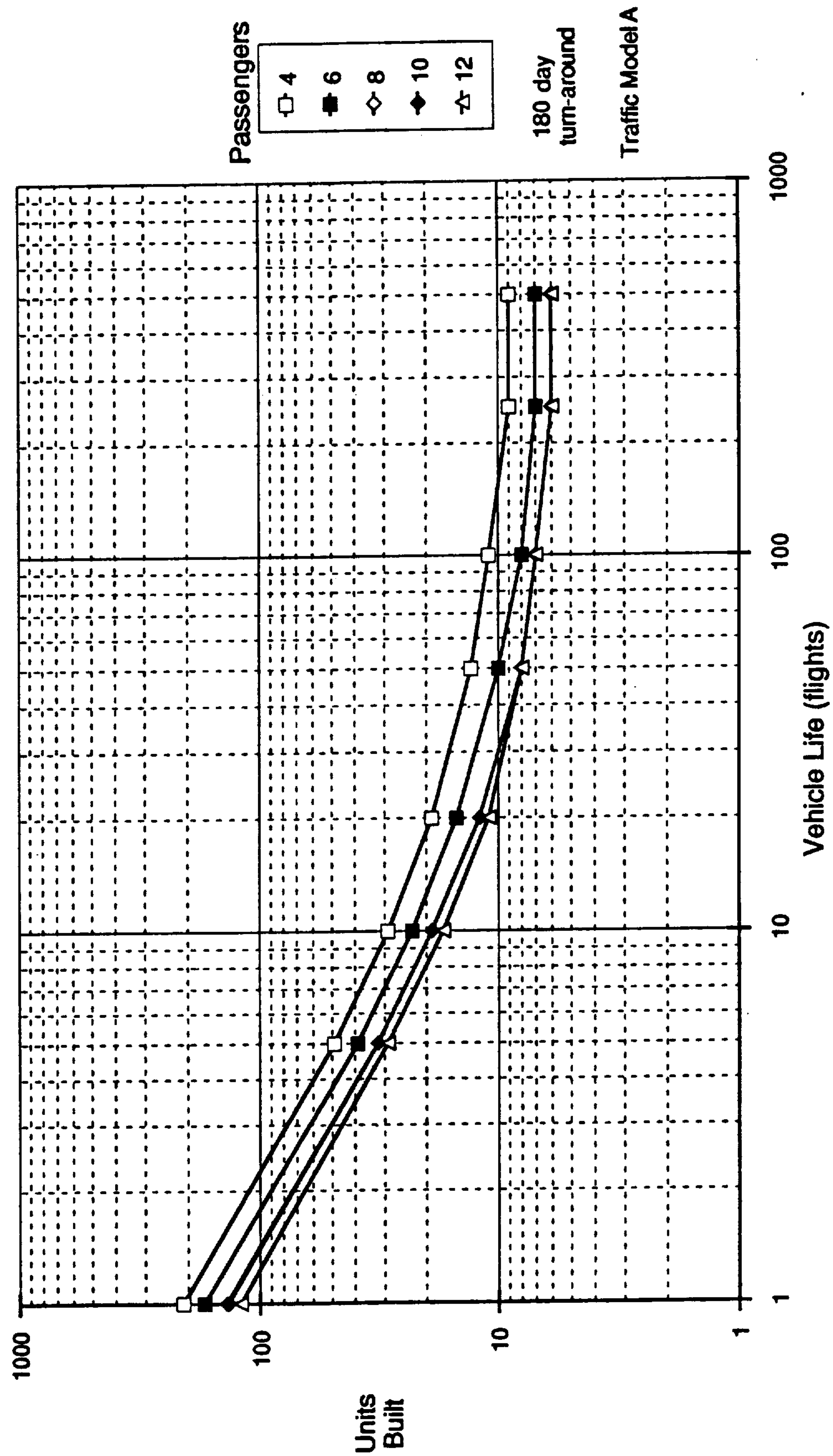

PLS's Built vs. Life
Passengers
4
6
8
10
12
30 day
turn-around
Traffic Model A
Units
Built
1000
100
10
1
Vehicle Life (flights)

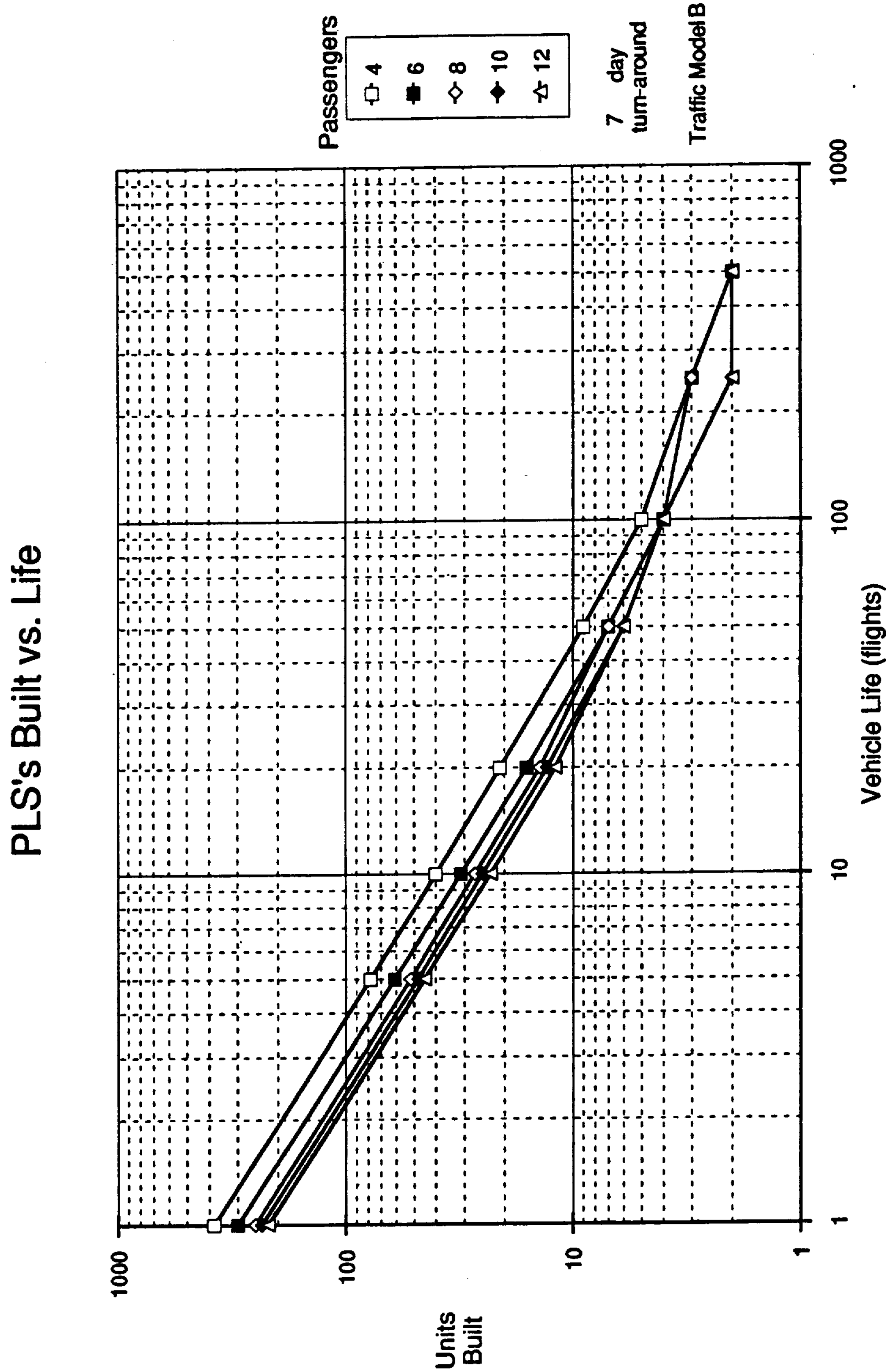


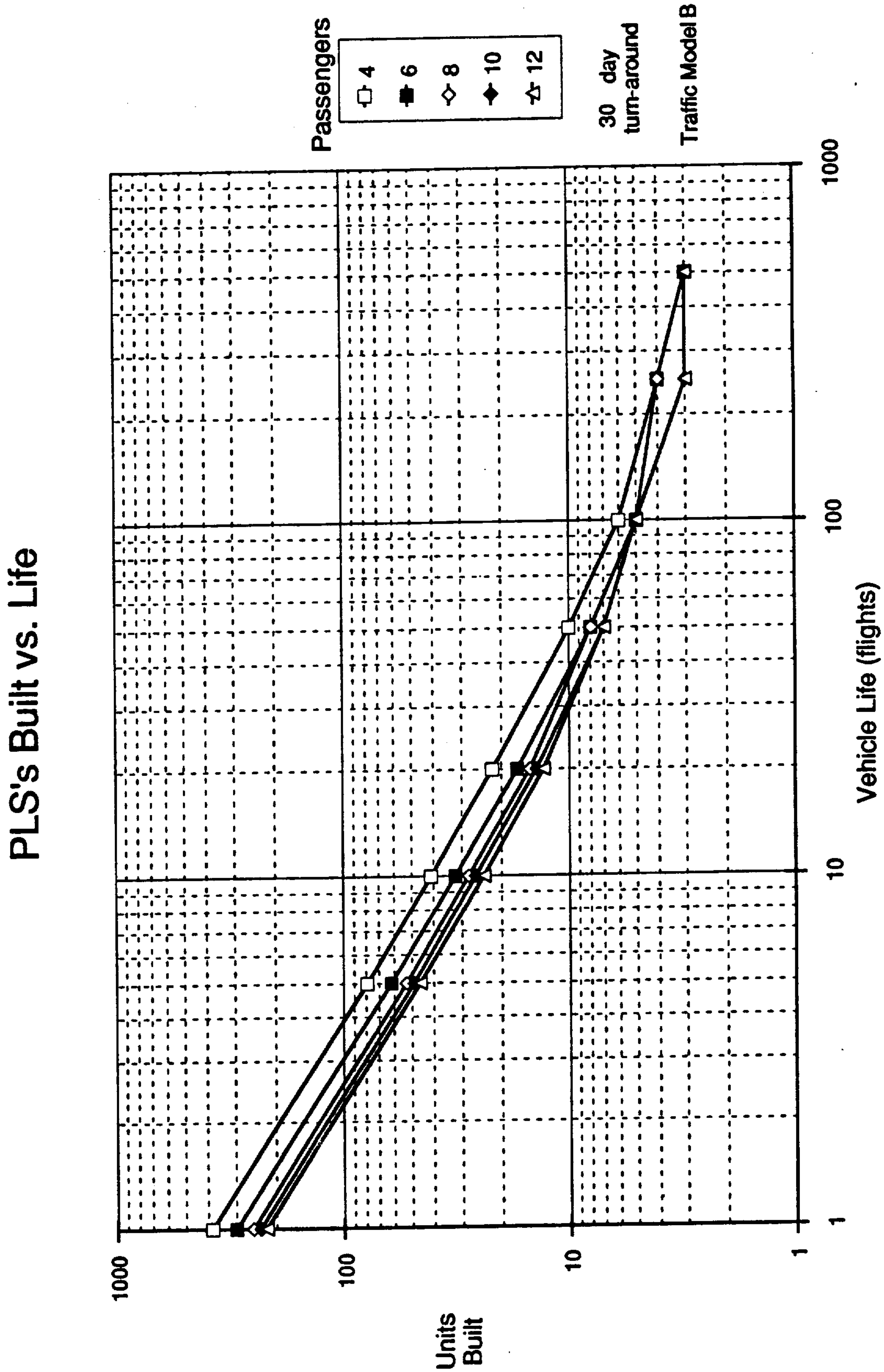
PLS's Built vs. Life
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000
Passengers
4
6
8
10
12
60 day turn-around
Traffic Model A


PLS's Built vs. Life
Passengers
4
6
8
10
12
120 day
turn-around
Traffic Model A
Units
Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

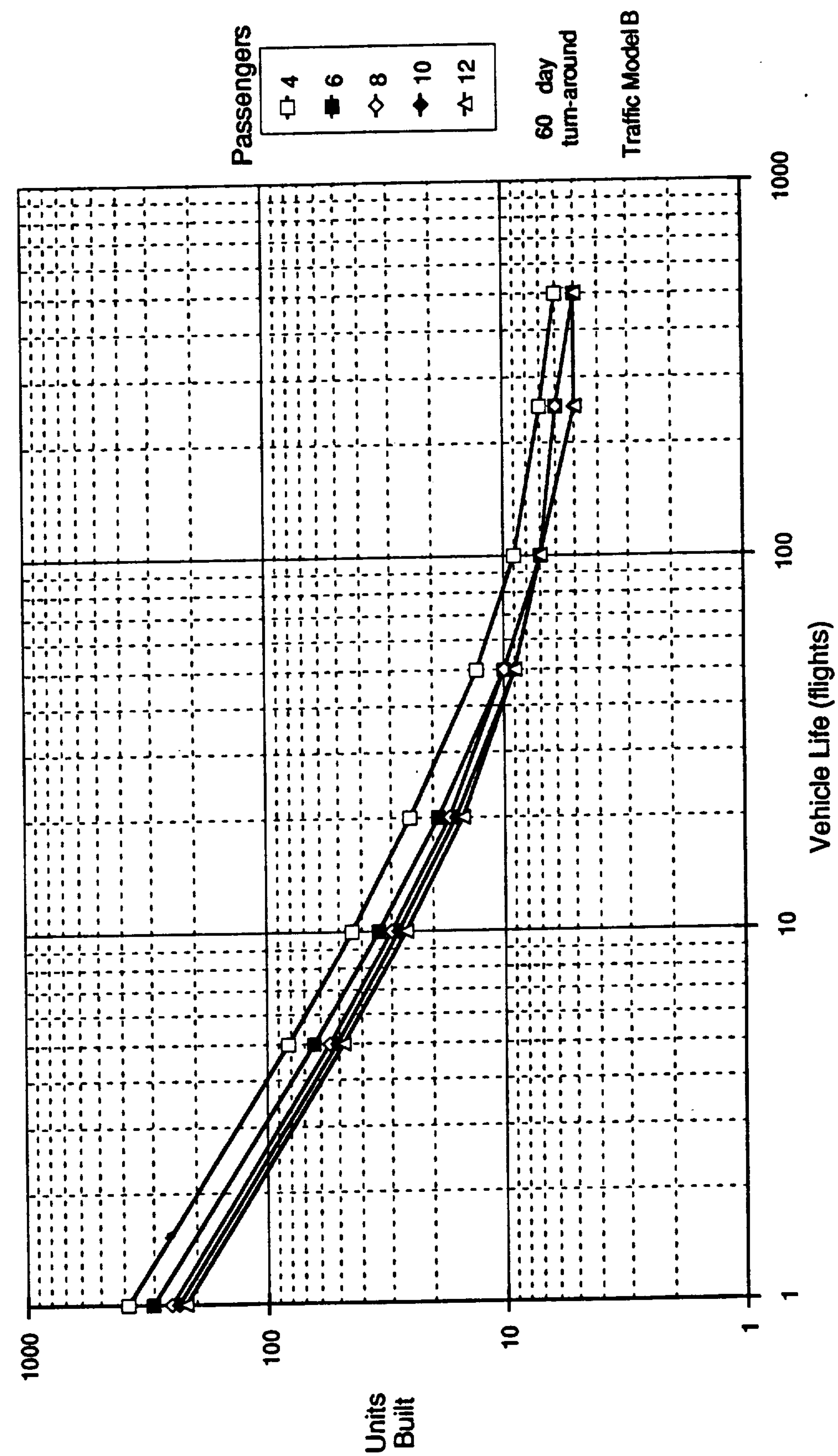
PLS's Built vs. Life

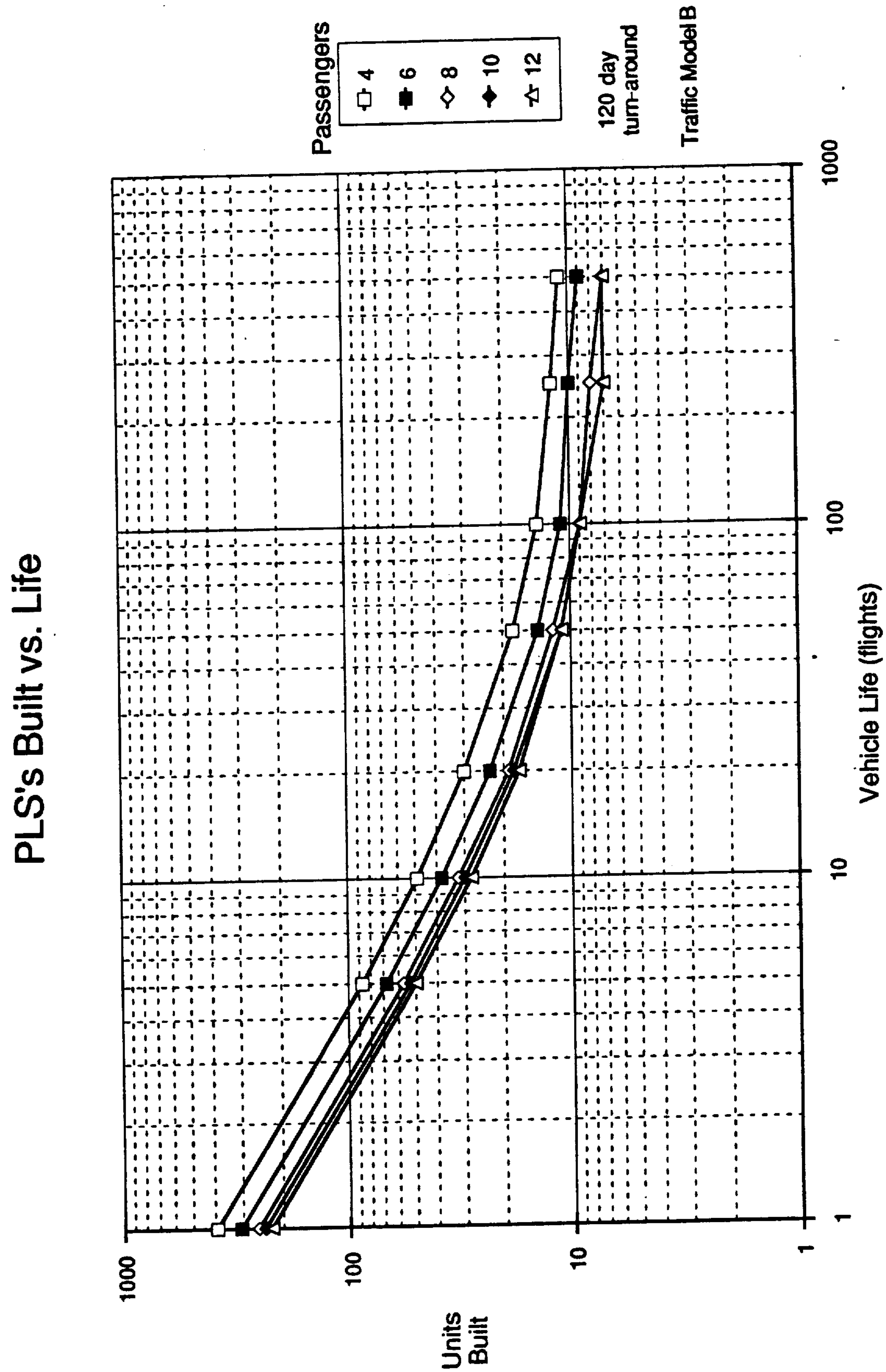


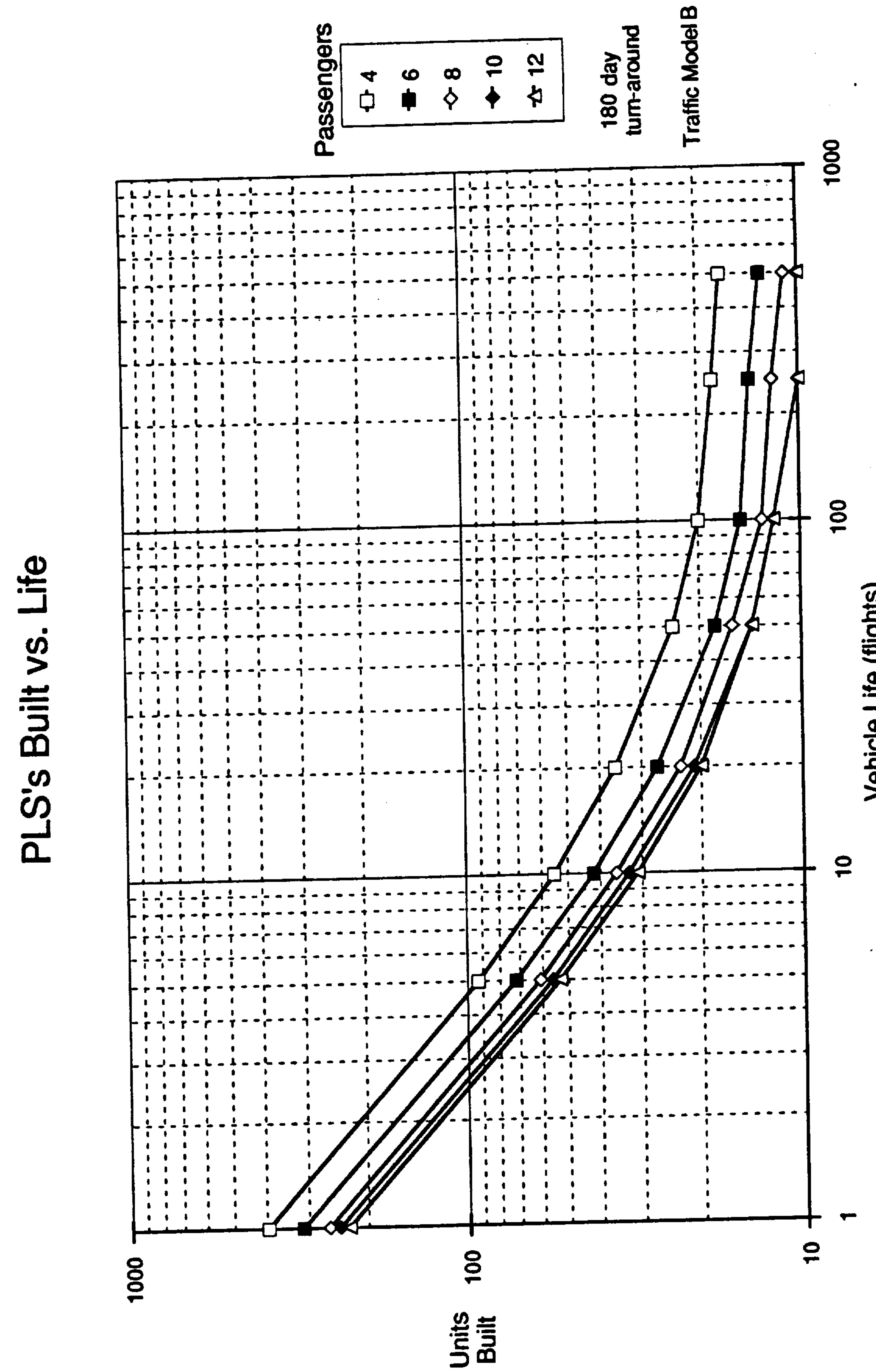

PLS's Built vs. Life
Passengers
4
6
8
10
12
7 day
turn-around
Traffic Model B
1000
100
10
1
Units
Built
Vehicle Life (flights)

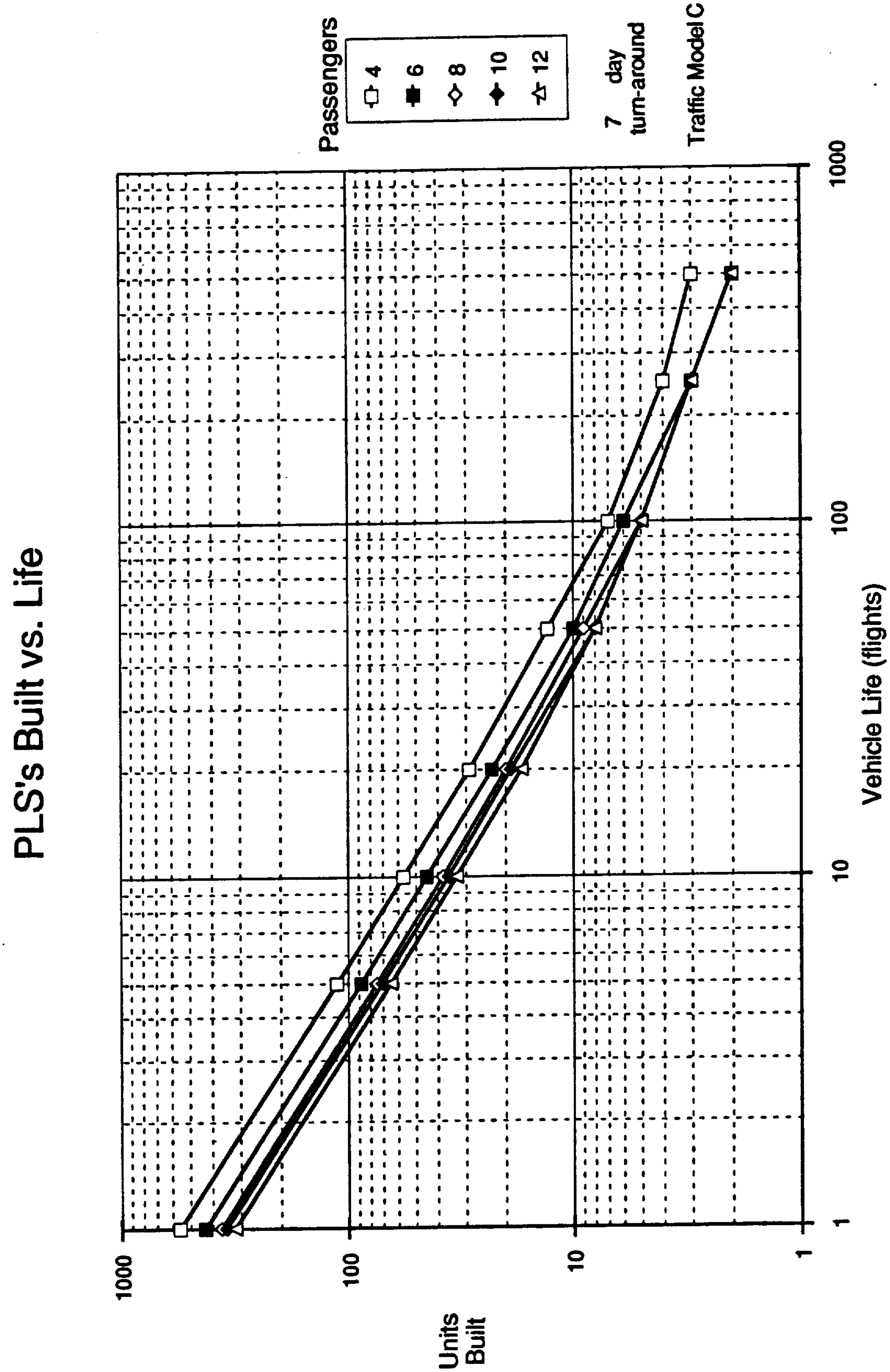

PLS's Built vs. Life
Passengers
4
6
8
10
12
30 day turn-around
Traffic Model B
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

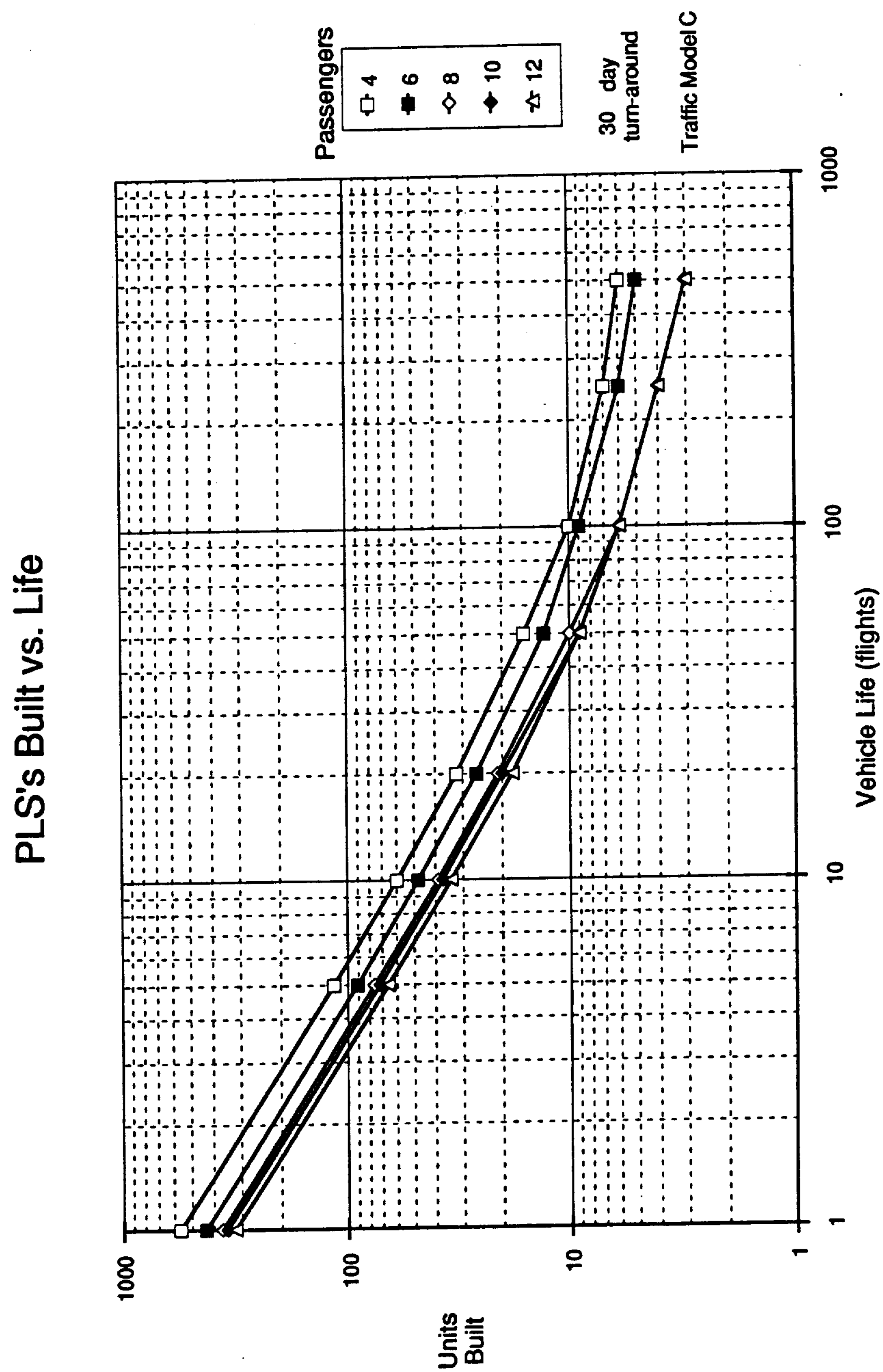
PLS's Built vs. Life

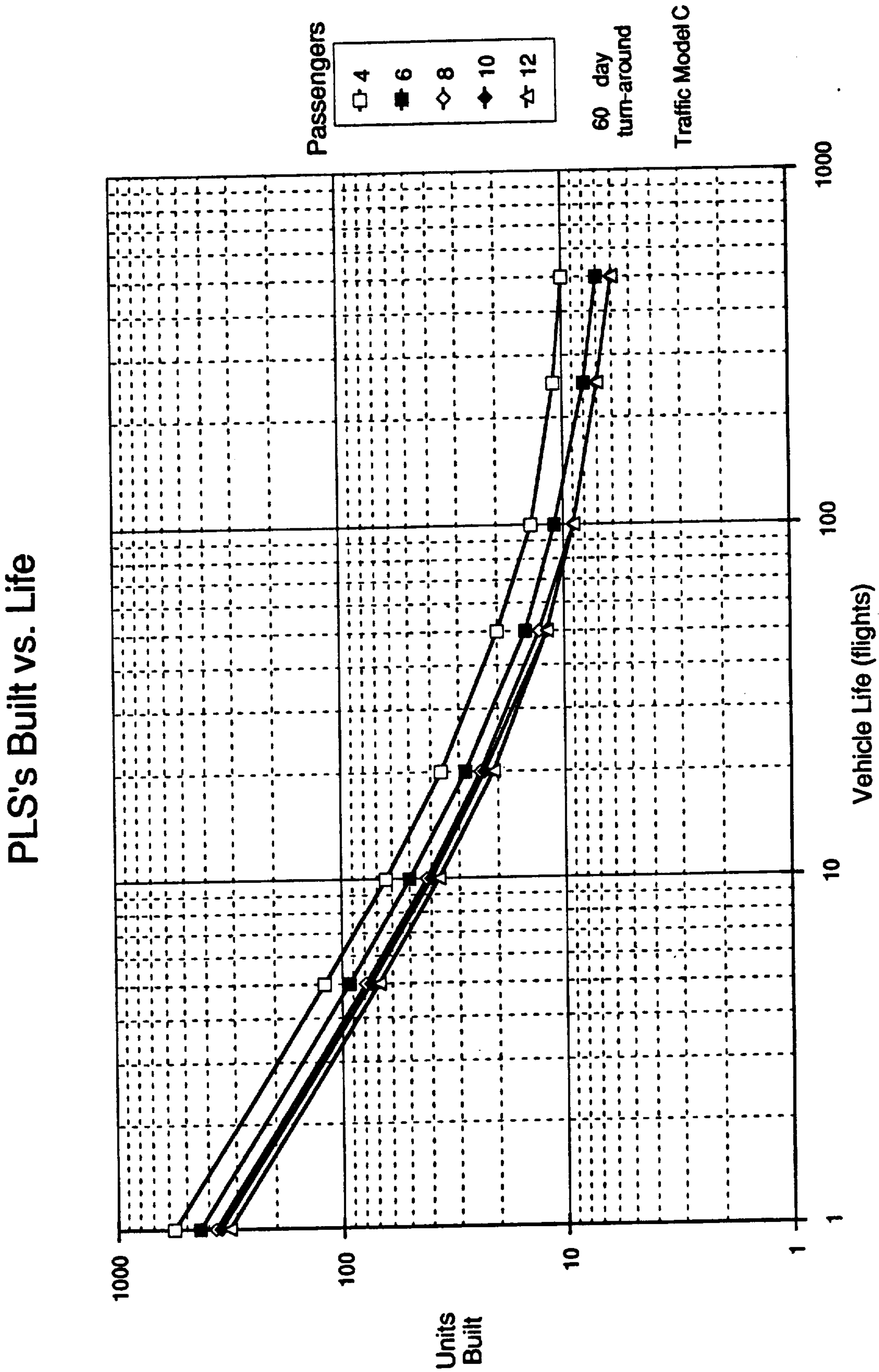



PLS's Built vs. Life
Passengers
4
6
8
10
12
120 day turn-around
Traffic Model B
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

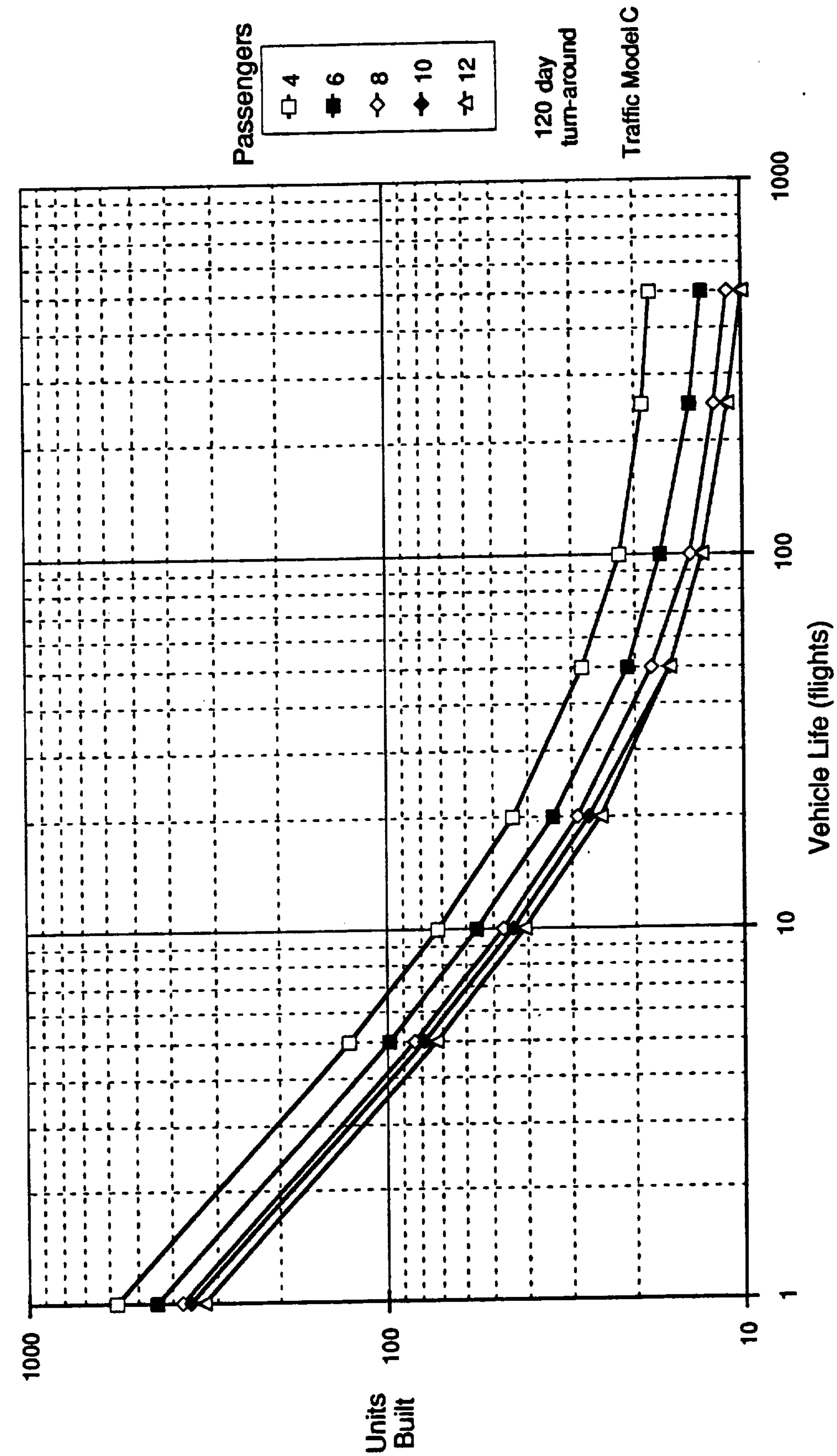

PLS's Built vs. Life
Passengers
4
6
8
10
12
180 day
turn-around
Traffic Model B
Units
Built
1000
100
10
Vehicle Life (flights)
1
10
100
1000

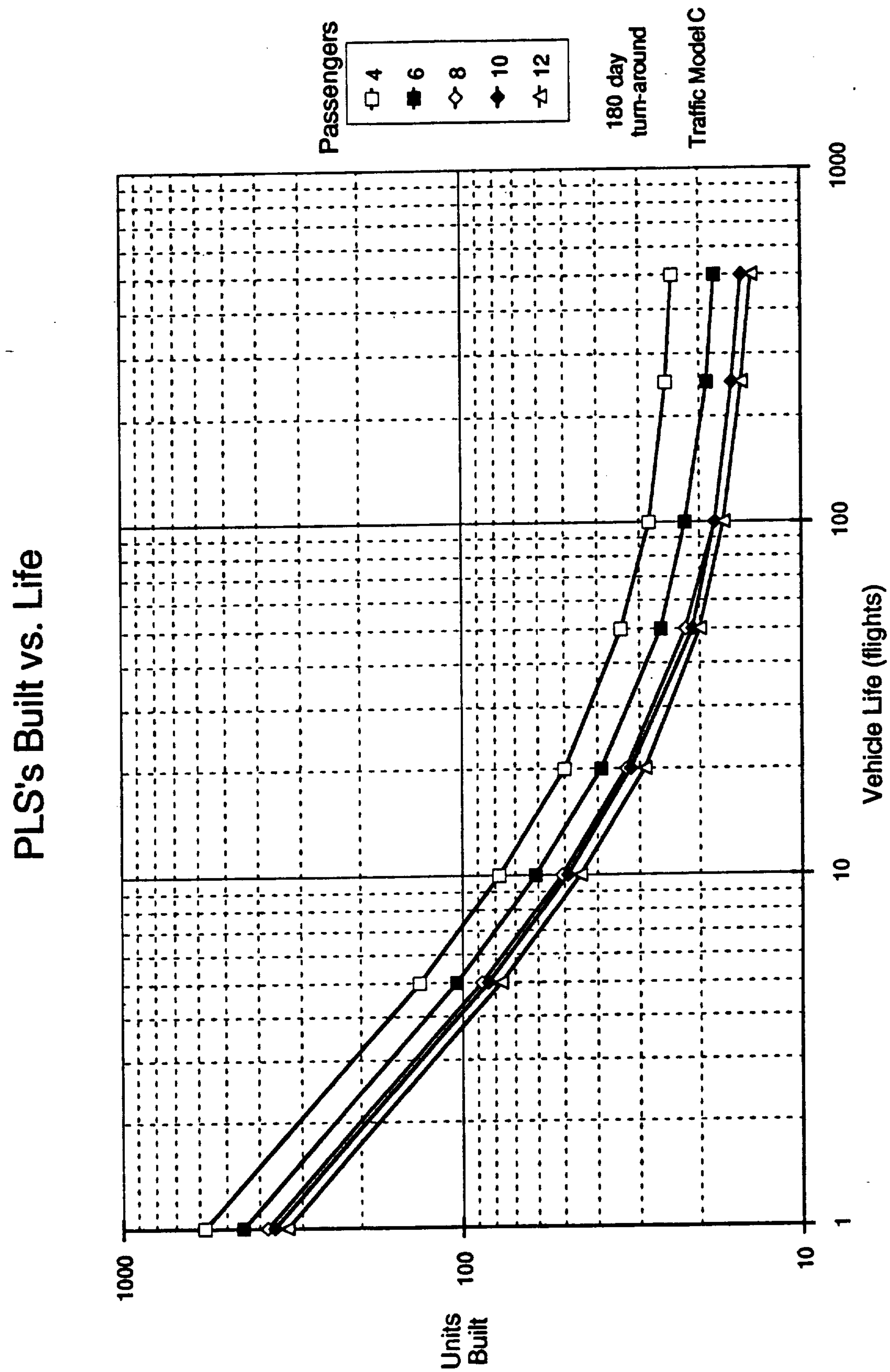

PLS's Built vs. Life
Passengers
4
6
8
10
12
7 day
turn-around
Traffic Model C
Units
Built
1000
100
10
1
Vehicle Life (flights)


PLS's Built vs. Life
Passengers
4
6
8
10
12
30 day turn-around
Traffic Model C
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

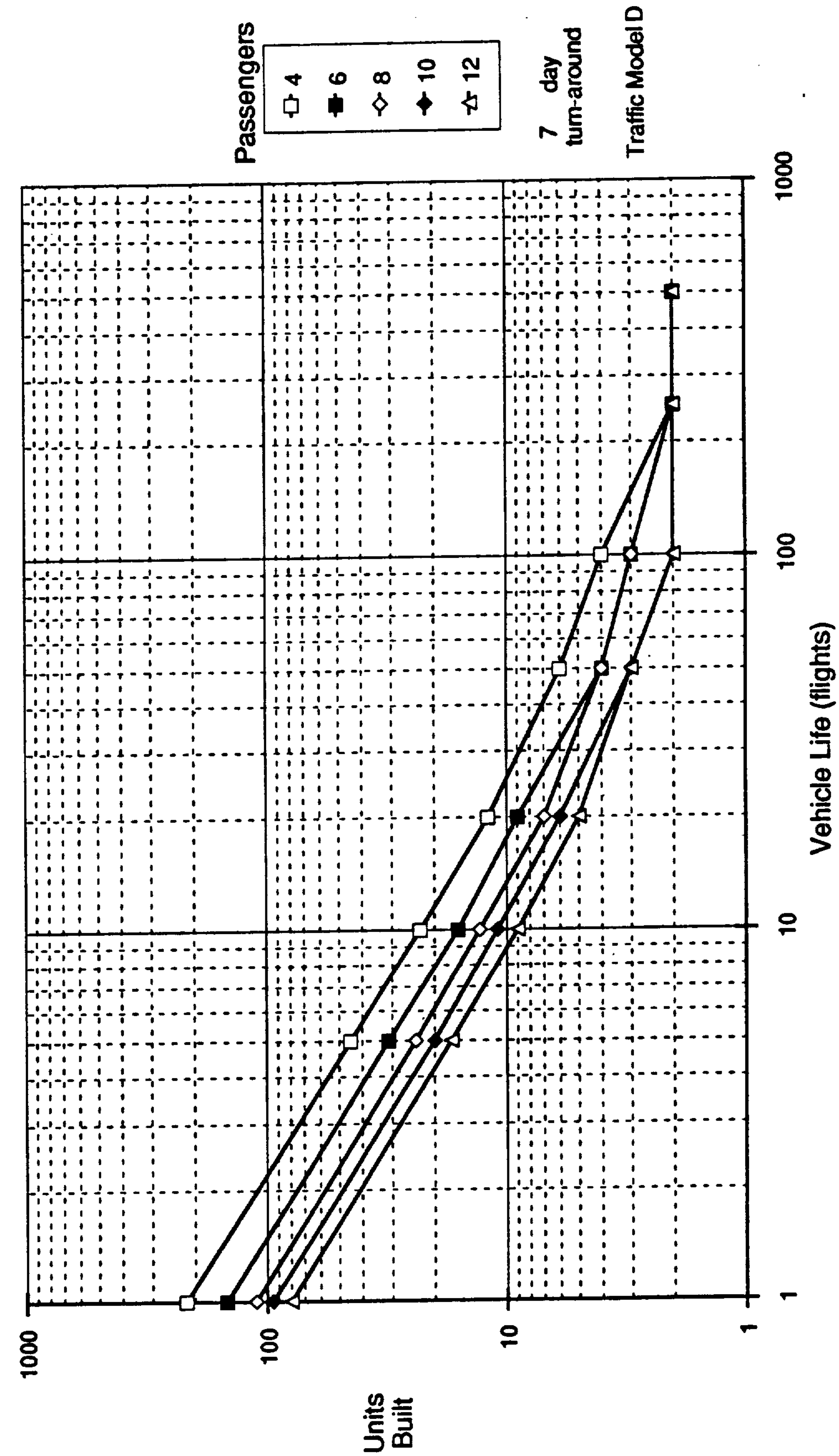

PLS's Built vs. Life
Passengers
4
6
8
10
12
60 day turn-around
Traffic Model C
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

PLS's Built vs. Life

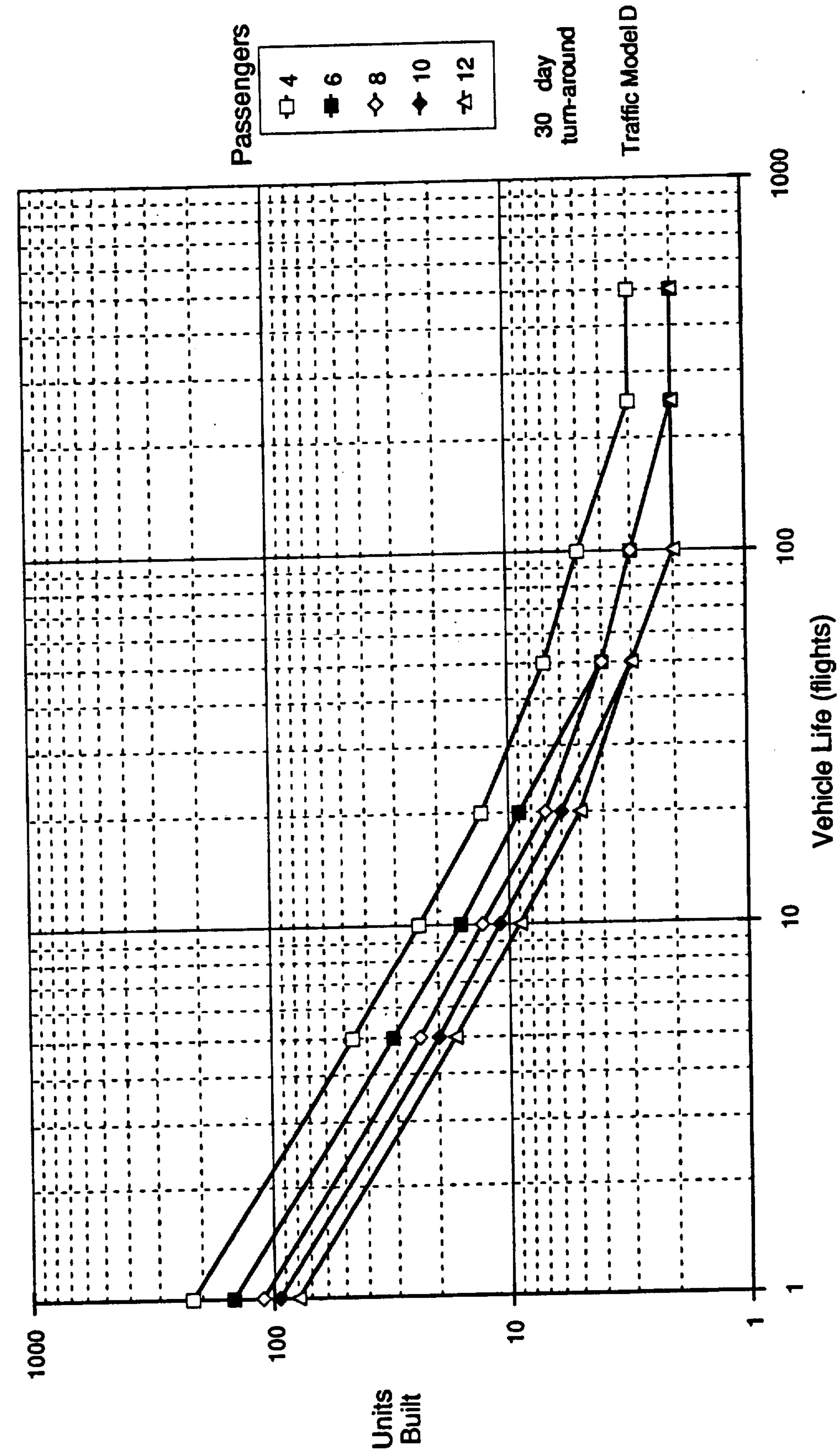


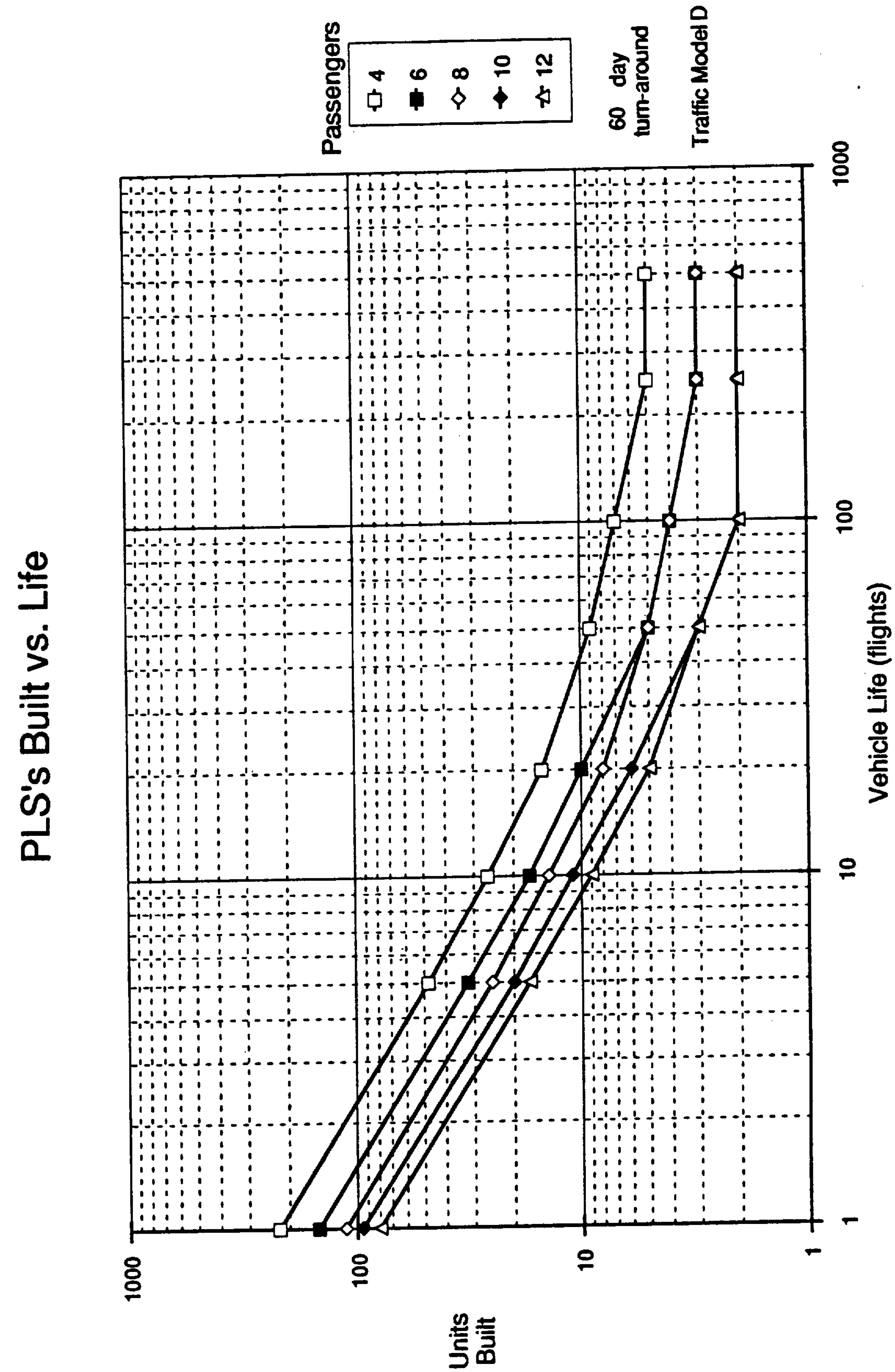

PLS's Built vs. Life
Passengers
4
6
8
10
12
180 day turn-around
Traffic Model C
Units Built
1000
100
10
1
10
100
1000
Vehicle Life (flights)

PLS's Built vs. Life

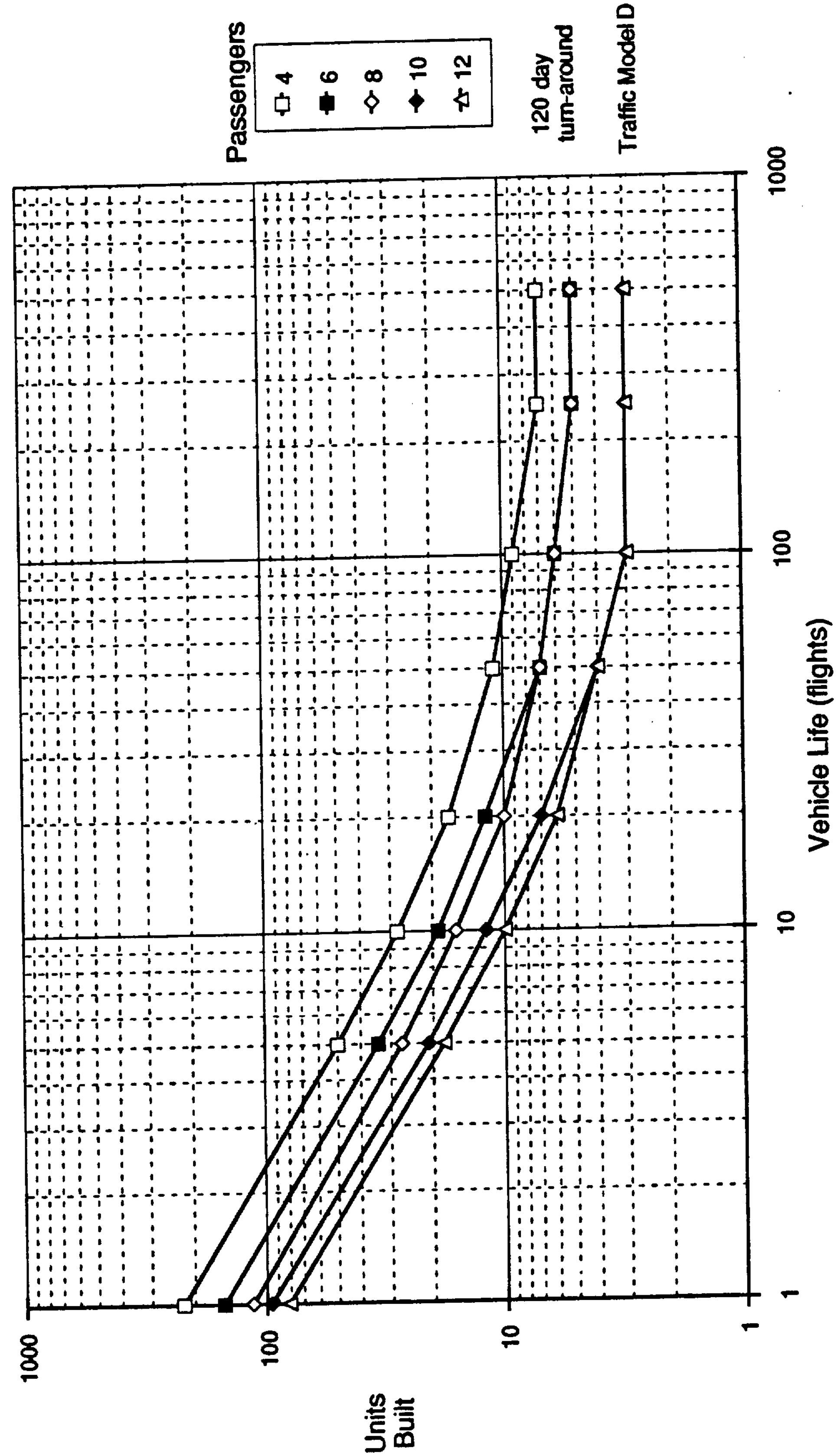


PLS's Built vs. Life

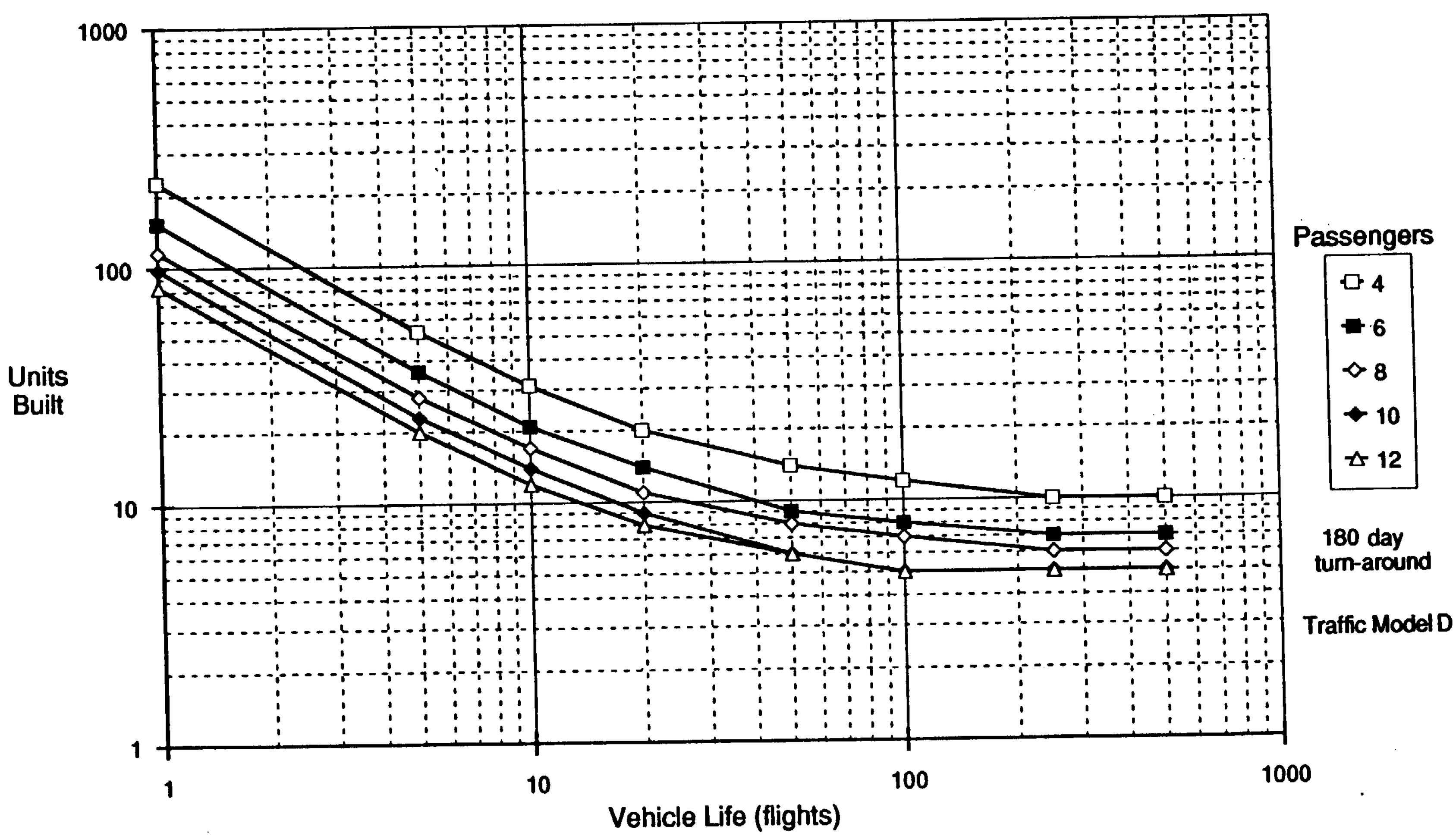


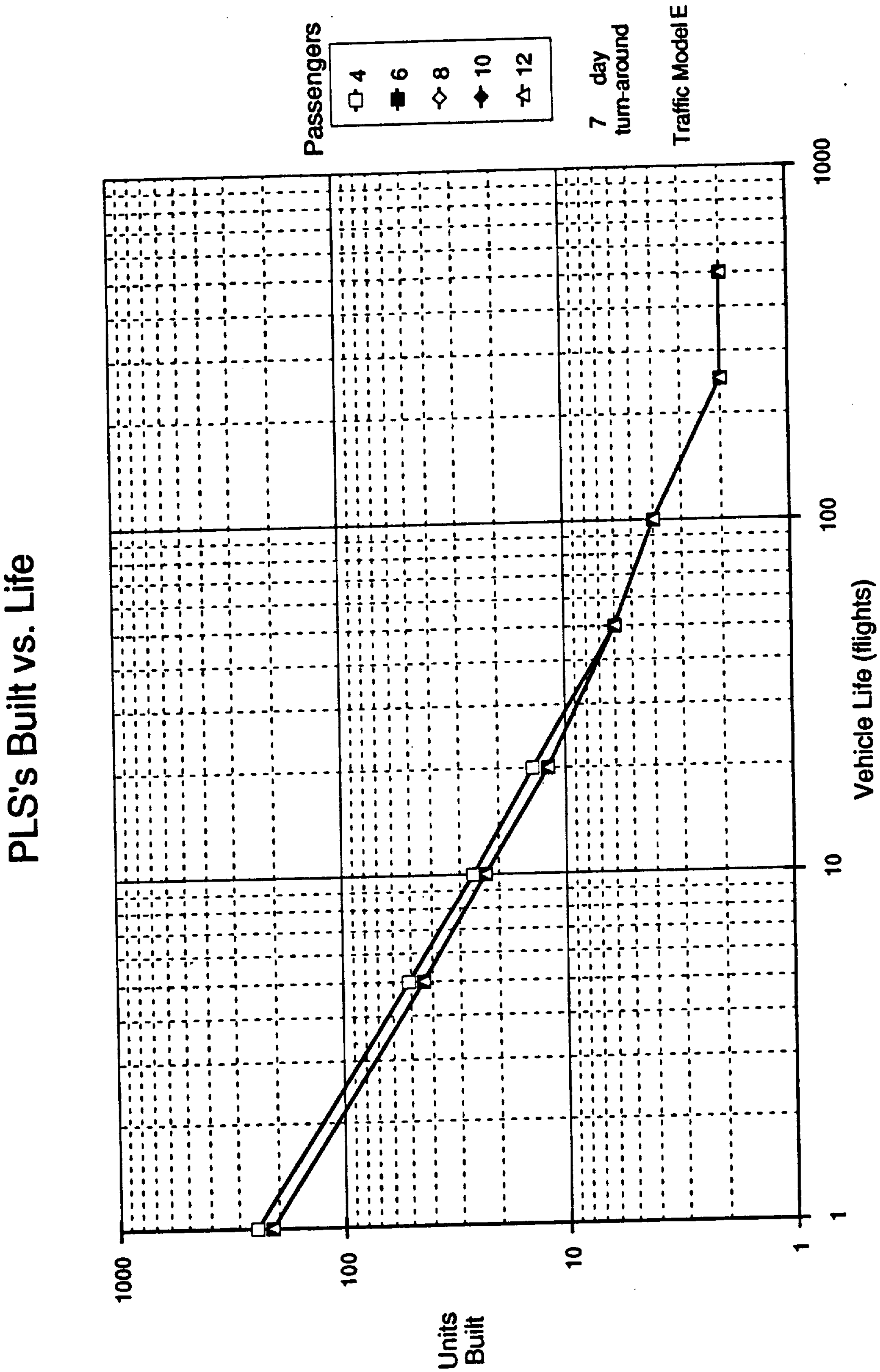

PLS's Built vs. Life
Passengers
4
6
8
10
12
60 day turn-around
Traffic Model D
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

PLS's Built vs. Life

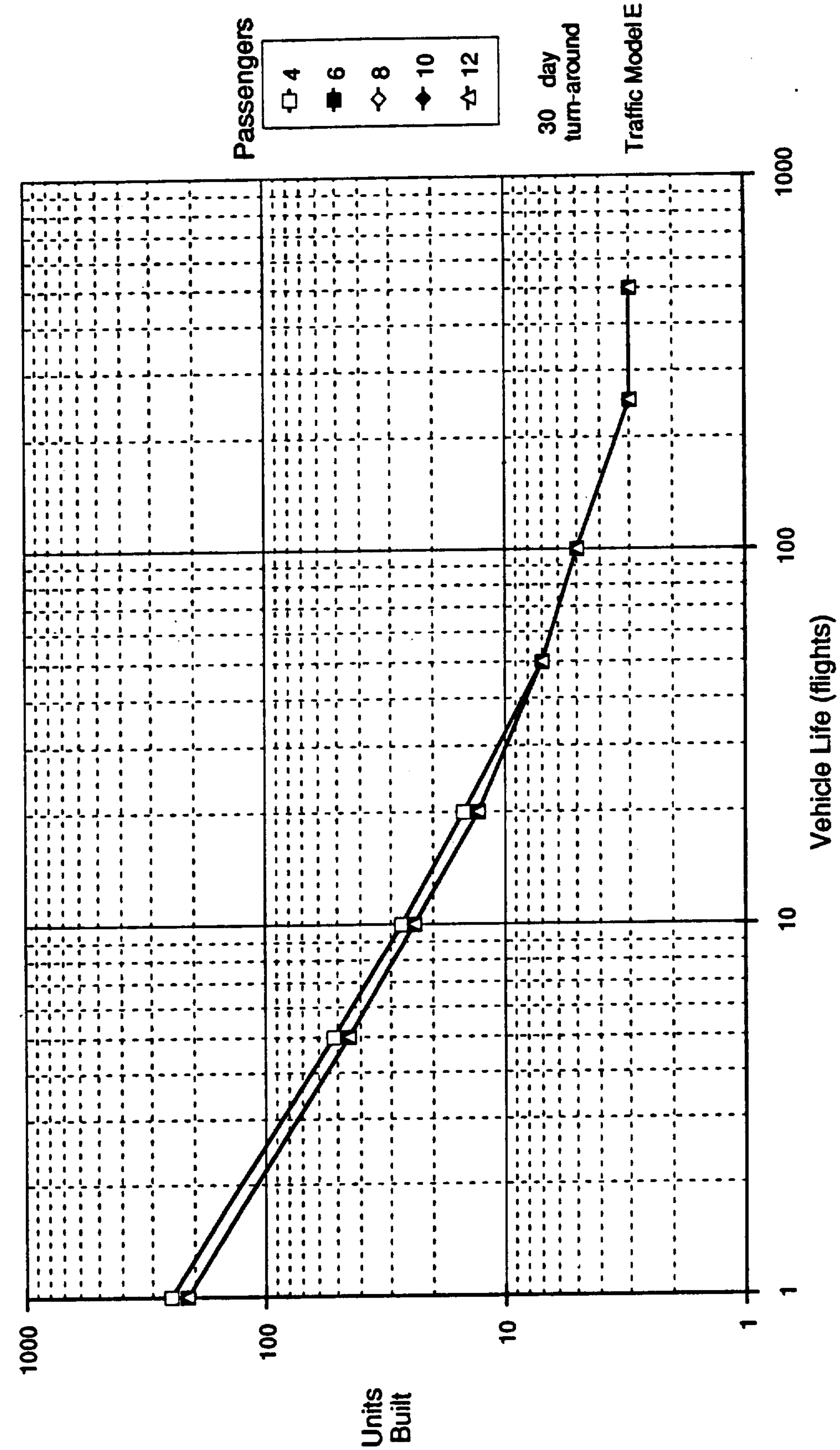


PLS's Built vs. Life

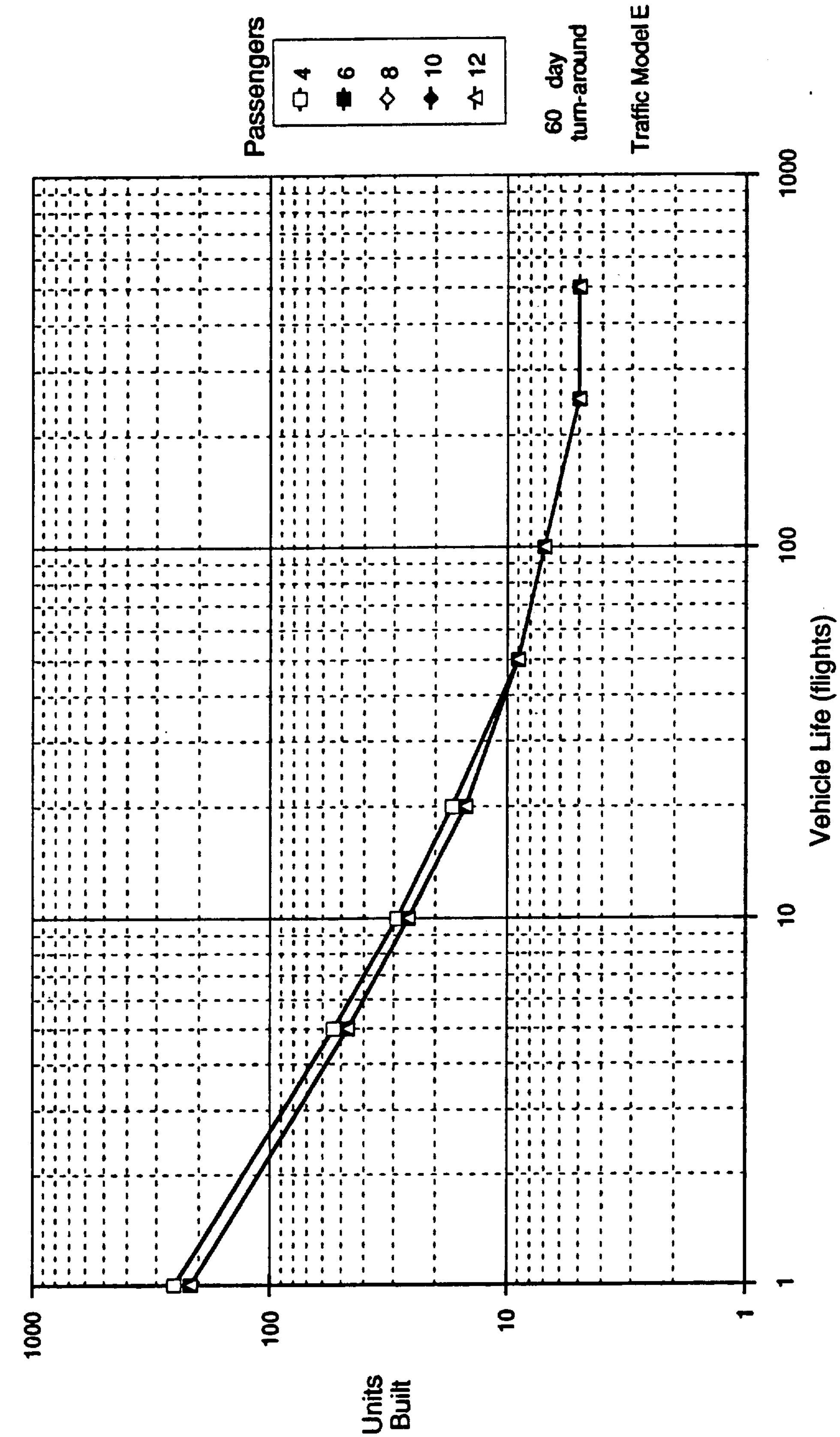


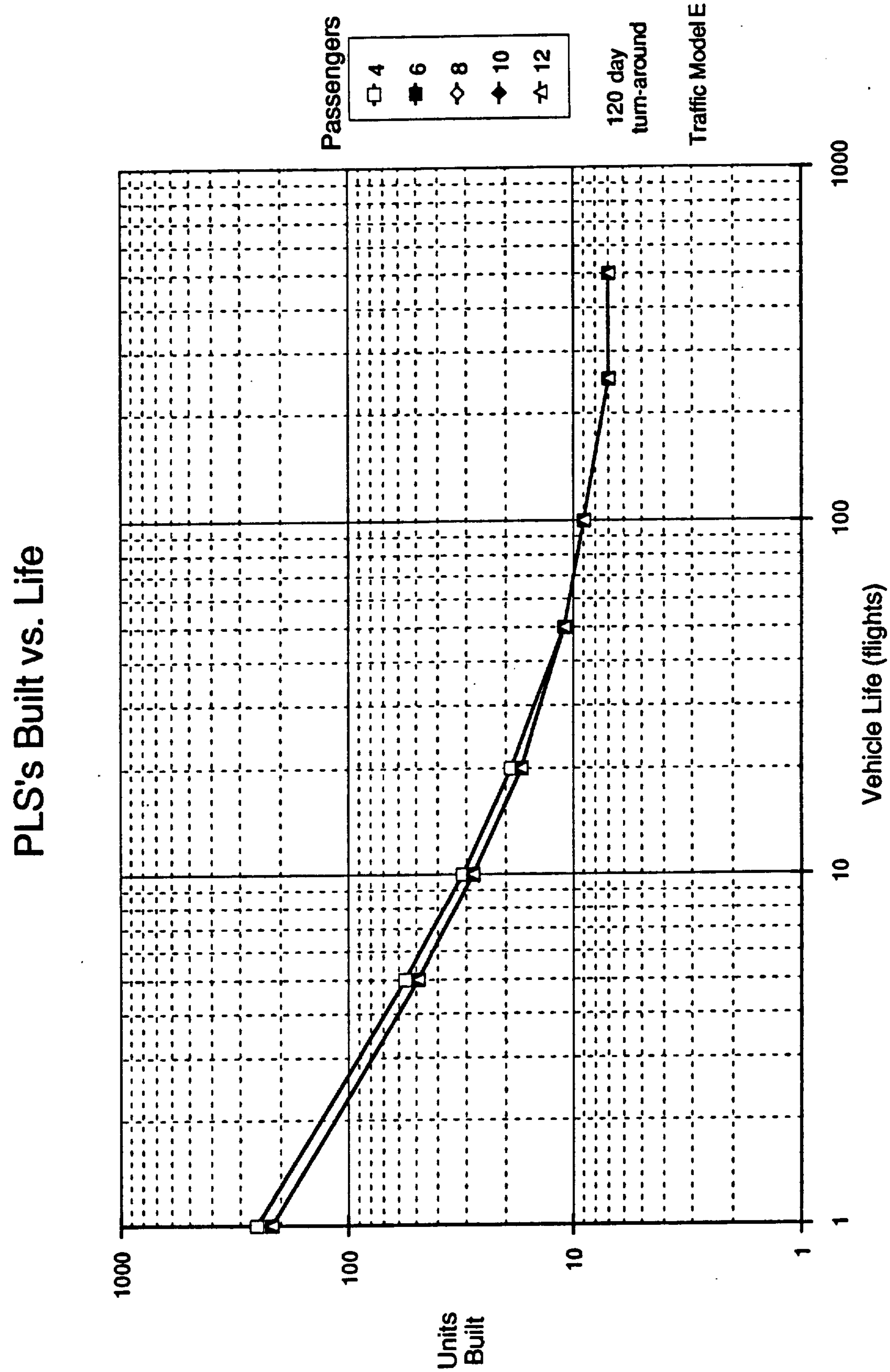

PLS's Built vs. Life
Passengers
4
6
8
10
12
7 day turn-around
Traffic Model E
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000

PLS's Built vs. Life

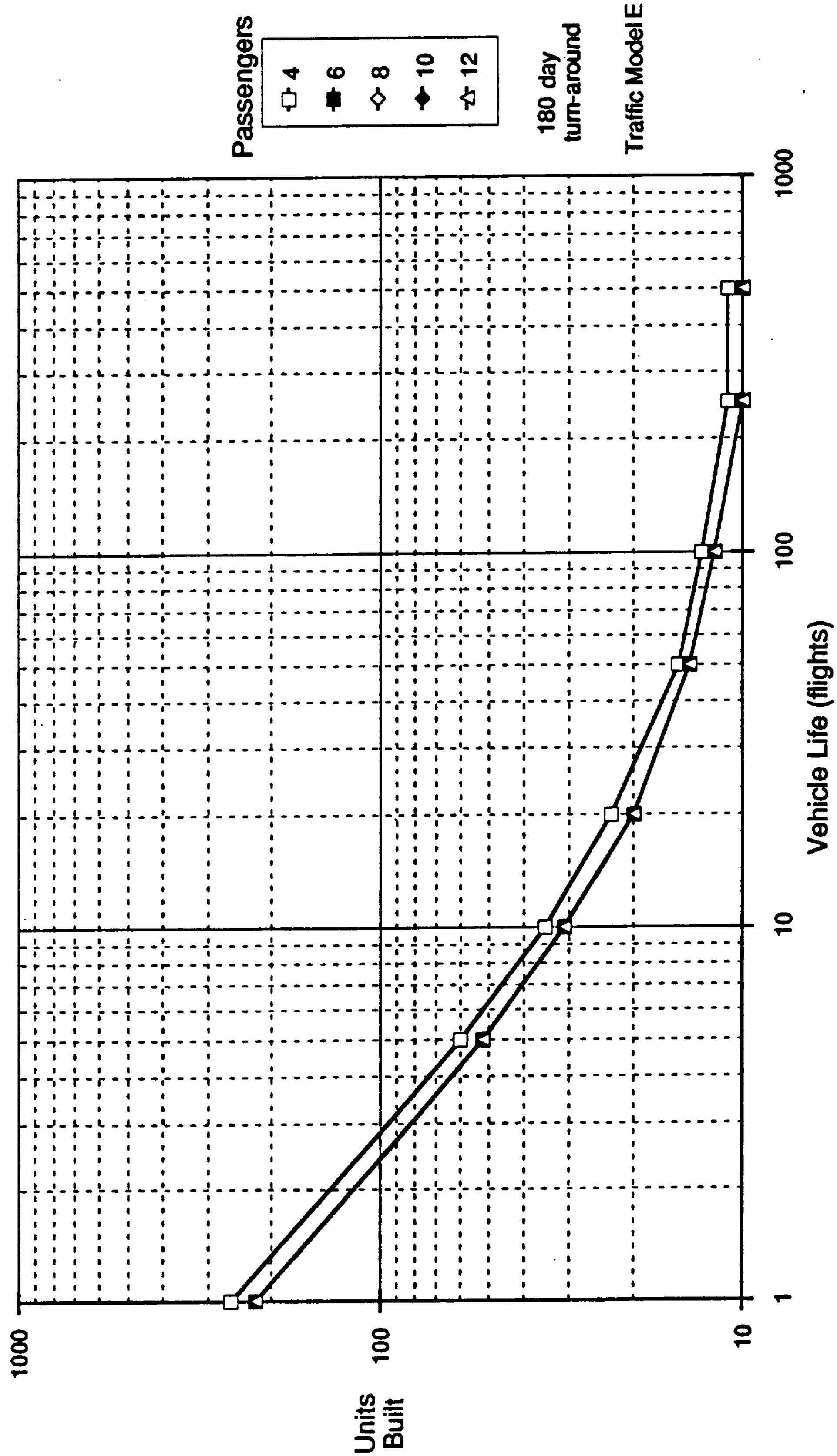


PLS's Built vs. Life




PLS's Built vs. Life
Units Built
1000
100
10
1
Vehicle Life (flights)
1
10
100
1000
Passengers
4
6
8
10
12
120 day turn-around
Traffic Model E

PLS's Built vs. Life



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APPENDIX B

ADDITIONAL CONCEPT EVALUATION

18 INTRODUCTION

At the completion of the initial contracted effort, Boeing was asked to explore a broader range of configurations. The question could be asked: "What would a PLS look like if the initial constraint of 'no wings, low L/D' was abandoned?" Building on the trade studies previously completed, a series of configuration concepts was defined and analyzed to provide the data that could answer that question.

In order to ensure a valid, "apples-to-apples" comparison of concepts, every effort was made to design the various configuration concepts using common subsystems. In some cases, however, operational scenarios must be different to exploit the best features of a given concept, and selective alterations to hardware elements were made.

The evolution of the SSF is continuing, and will continue for years to come. At the time of this additional effort (spring of 1991), there is move afoot to downsize the Space Station to include a crew of 4. It is open to debate whether this number would grow in the future, requiring a larger PLS for crew rotation support. In any event, the designs developed for this part of the study are shown in versions carrying both 4 and 8 passengers. It is assumed for cost estimation purposes that the flight rates remain the same.

19 DESIGN OPTIONS/CONFIGURATION PHILOSOPHY

The four configuration classes (hereafter referred to as Configuration I, II, III, and IV) represent the entire range of reasonable concept options. The exterior shape, and hence the aerodynamic performance, of each Configuration is distinctly different. In addition, each concept has an attendant operational philosophy that was conjectured to take maximum advantage of its physical attributes.

In attempting to provide data for valid comparisons, most of the aspects of the designs were held constant. System trades which resulted in the number of passengers, for example, were not revisited. Orbital performance requirements were held constant. Subsystem design selections were also largely identical between configurations. It was also assumed that a common launch vehicle selection was used.

Where the configurations are different, every effort was made to provide a traceable decision path. Obviously, features such as L/D, stability, and volumetric efficiency all are directly affected by the choice of shape. Other features, such as operational scenarios, are dissimilar by choice to take advantage of most desirable aspects of the designs. For example, in choosing a landing technique, it would not be prudent to develop a runway landing technique for a near ballistic vehicle. In a more speculative manner, general differences in growth capability, the degree of expendability, and program funding profiles were postulated based on trends evident from previous aerospace programs.

Configuration I

Configuration I represents a minimum performance design characterized by a low hypersonic L/D. Previously, it was shown (see sections 20.0 and 22.0) that a very low hypersonic L/D design presents significant designs concerns: high deceleration loads on the passengers, limited crossrange performance restricts the opportunities for landing at a given location from a random orbit, and the potential for high heating rates (depending on the specific shape). This class of designs do offer some significant advantages as well: shapes are typically highly volumetric efficient result in smaller, lighter configurations and tend to be simple (usually axisymmetric) which translates to lower manufacturing costs and a simplified aerodynamic analysis/verification program. Previous designs in the class include Mercury, Gemini, Apollo, Vostok, Soyuz, as well as unmanned designs such as the Viking and Galileo reentry shields.

Given the advantages and disadvantages of these types of shapes, the following scenario is envisioned that would best be served by Configuration I:

- A near term requirement for a PLS capability exists. Rapid deployment is desirable.
- Simultaneous budgetary demands exist. Development/deployment of the SSF, SEI, and a new launch system are already straining space budgets. The PLS development bill should be minimized.
- Future growth missions (such as satellite servicing) are indeterminate and are unlikely to be defined for years. Provisions for growth are not a design driver.

From this hypothetical scenario, the following design features are postulated:

- A simple, well understood shape will minimize development cost and risk. Manufacturing costs for the outer shell should thus also minimized.
- Water landing (splashdown) will simplify the landing system considerably, both in hardware and in GN&C software. Ballistic parachutes would be used to decelerate the vehicle. This approach would also the simplify the effort associated with verifying range safety procedures, assuming the landing zone is a large body of water not immediately adjacent to a populated land mass.
- Maximum use of existing subsystem hardware will be emphasized. For example, OMS and RCS systems will feature existing components of the Shuttle Orbiter's bipropellant system.
- Expendable systems will be included wherever the development of the reusable equivalent would create an appreciable cost or development schedule impact. For example, if a refurbishable (after saltwater immersion) TPS tile requires a new coating application method, initial operations could use an expendable ablator TPS.

Configuration II

Configuration II is a compromise between the simplicity (manufacturing, analysis) of Configuration I and concepts driven solely by the pursuit of high aerodynamic performance. In the previous study effort, it was shown that even moderate L/D shapes can reduce the "g's" and provide sufficient crossrange maneuver capability for most all the envisioned PLS missions. The reference biconic concept explored in the previous study effort represents a typical mid L/D shape.

The following scenario forms the basis for exploring the types of designs collectively covered as Configuration II:

- PLS is envisioned as a long-term, routinely operable system with inherent growth capability to future missions in addition to SSF crew rotation. As in the aircraft world, a higher "up-front" DDT&E effort (compared to the Configuration I scenario), will be offset by reduced operations costs in the long run.

- Maximum flexibility in launch vehicle integration, minimum transportation and facilities infrastructure impact, and inherent system safety are all central to the design philosophy.

From this broad scenario, in conjunction with the concept of an aerodynamically simple shape (moderate L/D), these design features are suggested:

- Precision land landing will keep the recovery, refurbishment, and transport costs to a minimum. Some form of impact attenuation system is required to limit terminal deceleration levels on the passengers.

- Moderate L/D shapes tend to have inadequate subsonic performance to horizontally land on a runway; a predominantly vertical landing could potentially provide for a wider selection of landing sites than to use just paved runways.

- High volumetric efficiency and careful selection cf the exterior shape should be sized where possible to fit (without modification) onto/within existing transportation and facilities.

- Subsystem selections should be based primarily on operability and safety.

Configuration III

Configuration III represents a design featuring maximum performance capability while striving for a high volumetric efficiency. Many "simple" shapes can produce significant hypersonic L/D and could qualify for this category. Indeed, hypersonic aerodynamics is more a function of projected area, angle of attack, and fineness ratio than features from subsonic aircraft associated with efficient aerodynamics (such as wing profile, aspect ratio, etc.). Lifting bodies, conceived of to specifically address the maximization of hypersonic performance and volumetric efficiency, are the logical culmination of the work on this category of configurations.

A hypothetical scenario that would best be served by Configuration III is as follows:

- As was stated in Configuration II, the PLS would be a long-term, routinely operable system design with inherent safety and minimum ground operations features.
- A requirement for large crossrange capability exists. This could result from the need to deorbit immediately from any random orbital location and land at a few designated landing sites. Alternatively, large crossrange capability could also be used to land at locations significantly more northerly than 28.5° latitude (opening up most of the continental United Stated as potential landing areas). "Once around" abort to launch site trajectories could also be considered with this capability.

Design features associated with a lifting body PLS design would include:

- Subsystem selections should be based primarily on operability and safety.
- Since most of the reentry is flown as a lifting trajectory (like an aircraft), an aircraft type runway landing may be desirable. While this approach does eliminate the need for a separate deceleration system, subsonic flying qualities of lifting body designs tend to be marginally acceptably. The perceived value/safety of a runway landing is difficult to quantify from a kinetic energy standpoint, a vertical descent with impact attenuation may be preferable.

- If the nominal landing is a horizontal runway lander, an auxiliary water recovery system is required for launch aborts. Terminal horizontal velocities are too high to "ditch"; a small parachute should be sufficient to land vertically on the water.

Configuration IV

Configuration IV envisions a class of designs where operability is paramount. Aircraft operations, including robust runway landing capability, are emulated wherever possible as to capitalize on the maturity of systems that have been proven to be safe and efficient to repeatably operate. Outwardly, the most significant feature of Configuration IV will be a distinct wing and control surfaces, sized to provide low landing speeds and robustness in variable weather conditions. Hypersonic performance is not emphasized, but winged designs typically have significant inherent capability resultant from large projected wing areas.

The best operational scenario for Configuration IV would include the following:

- As in the previous Configuration (II and III), PLS is designed for long term, routine operations.

- In pursuit of the "aircraft world" analogy, sufficient inviolate budgetary planning is conducted whereby development, testing, and spares allocations are met in full. This philosophy has been shown to reduce operations costs to an absolute minimum.

- A tangible benefit to runway landing operations exists. Costly delays or refused reentries due to landing zone weather conditions would be eliminated by providing adequate system robustness to either land in marginal weather (as in aircraft) or to fly to another standard runway (no specialized support equipment required at the landing site).

From this scenario, unique design features to Configuration IV include:

- Aerodynamic surfaces consistent with the goal of landing speed of less than 175 kts with capability to handle 22 kts of crosswind at landing. Ideally, the vehicle should exhibit very good subsonic handling characteristics (3 or better on the Cooper-Harper scale).

- Durable TPS capable of operating with surface flaws (dents, scratches) incurred during normal aircraft handling and weather conditions is required. Only visual inspections between flights would be necessary.
- Subsystem accessibility is proportional to it's MTBF. No access should require clean room conditions.

20 CONCEPT DEFINITION

20.1 Configuration I

Configuration I represents the lowest hypersonic L/D concept option. To avoid excessive "g" loading on the passengers during reentry, the design should feature an L/D of around 0.3 to 0.4. In keeping with the design philosophy discussed in the previous section, the shape should be as simple as possible, perhaps even identical to a previous capsule design so as to minimize development costs.

Concept Design - The selected external configuration is a blunt body with a conical afterbody, similar to the Apollo Command Module (See Figure 20.1-1). The large radius heat shield, at 17 ft. in diameter, was intended to be as large as possible (reducing ballistic coefficient and local aerothermodynamic heating). The maximum diameter was constrained by transport envelope (e.g. C-5). The sidewall angle will determine c.g./c.p. sensitivity (and thus lift) and will also determine the degree of TPS required to cover the exterior aft of the blunt shield. A sidewall angle of 20° provides the transition between the heat shield and the 80 inch docking/berthing collar at the apex of the conical section. Since the vehicle enters blunt end first, the personnel would have couches oriented with their backs toward the heat shield. During ascent, the conical section faces forward, requiring only a small nose fairing to cover the docking equipment.

Including the OMS and radiator into the basic vehicle volume would have several drawbacks. First, the vehicle volume would expand to result in the inability to use airborne transports. Secondly, there would still be insufficient surface area to use a simple, fixed radiator, requiring a deployable scheme of some sort. Thirdly, development costs could be reduced by using an expendable OMS/radiator/launch vehicle adapter (a "service module") unit that doesn't require the OMS engine to penetrate the base heat shield. Also, growth missions for a simple capsule (such as a lunar transfer cab) may require different ΔV requirements best served by an external, modular OMS.

Subsystem arrangement is basically identical to that discussed in the previous report sections. The baseline landing technique would be a water landing using ballistic parachutes and no distinct impact attenuation. In the thermal protection area, one design option to consider is to use an ablator which would alleviate some of the

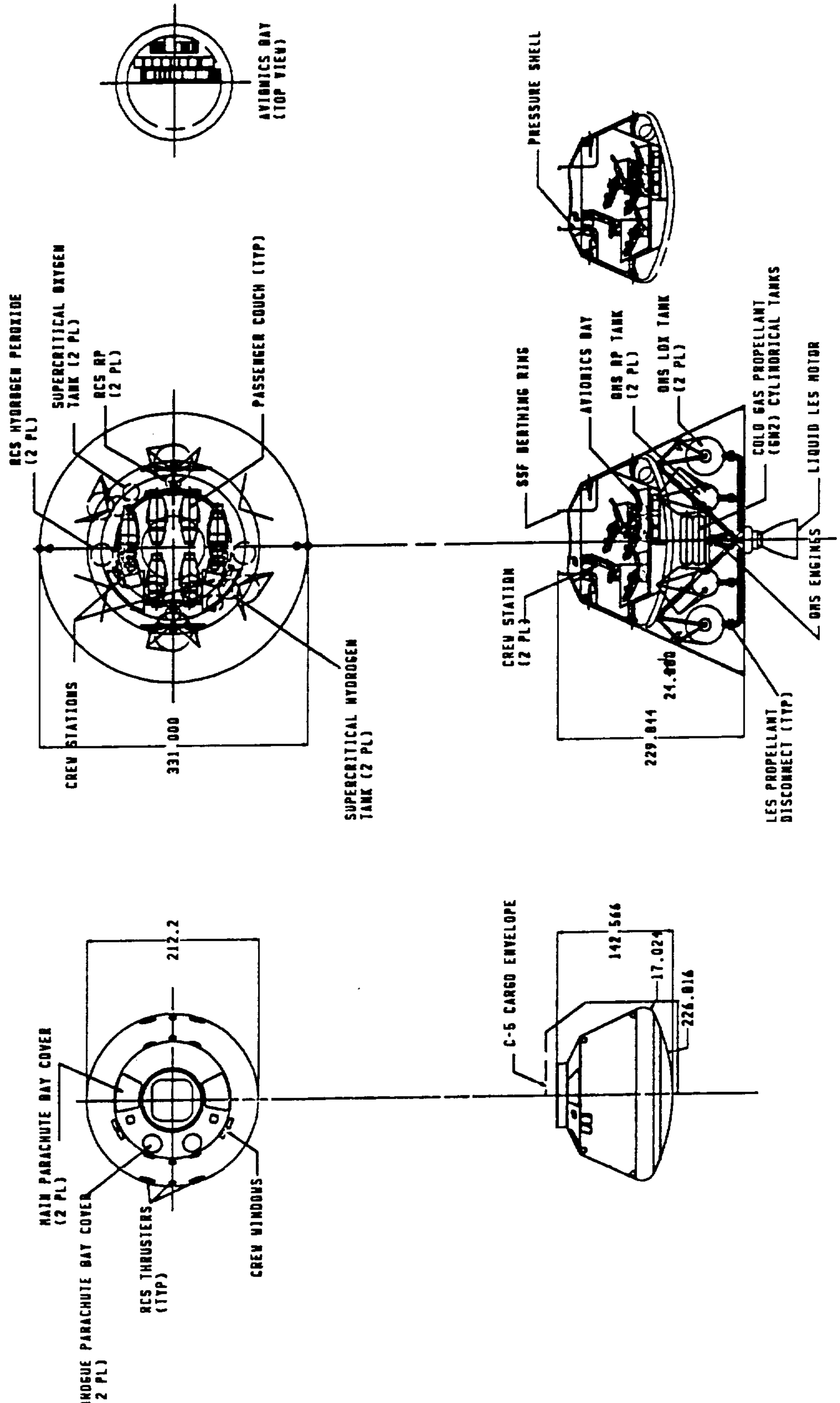


Figure 20.1-1. Configuration I General Arrangement (10 Person)

design issues associated with refurbishment of TPS that has been immersed in salt water.

To provide good pilot visibility for docking or landing function, the two pilot - astronauts are located high up in the conical section, close to the docking ring. The seats would be two position couches, laid back during ascent (when the windows are covered anyway). Multiple windows provide excellent viewing in several directions.

A disadvantage of this shape is the difficultly in locating the RCS thrusters that would exhaust in the direction of the heat shield. These thrusters are used primarily to move the vehicle towards the docking collar. Penetrations on the heat shield itself are undesirable, and the sine losses associated with sidewall slope make scarfed installations inefficient. One alternative would be to mount the thrusters on the "service module". This would mean throwing away thrusters and additional plumbing runs from the RCS tanks inside the reentry vehicle. Another alternative would involve a flip out panel on the sidewalls with the RCS thrusters built into the door. During reentry, when these thrusters aren't required anyway, the door is closed. The obvious drawback to this scheme is more complexity and the inferior reliability of rotary fluid joints.

Operational Description - At launch, the PLS rides atop the ELV to a nominal insertion orbit, where the booster and the LES are jettisoned. The OMS raises and circularizes the PLS orbit to the desired orbit. The radiator is operating as the primary means of thermal control.

For DRM1, an automatic rendezvous and approach to the SSF is performed using the RCS and proximity operations thrusters where the SSF MRMS would grapple the vehicle and berth it to the SSF. Following crew rotation, the procedure is reversed until the PLS is outside of the SSF control zone.

At the time for deorbit, the OMS engines are fired and the vehicle begins its descent. The "service module" is jettisoned and burns up as it reenters. The personnel section reenters along a nearly ballistic trajectory. A drogue chute is deployed at low supersonic speeds to slow and stabilize the vehicle before three ballistic parachutes are deployed. The vehicle lands in the water in a preplanned recovery zone and is righted by small flotation bags. Both hatches should be above the water level for egress.

A recovery team led by helicopters locates the capsule and renders any immediate aid required. A recovery ship reaches the vehicle soon thereafter and winches the vehicle onto the deck (similar to the ALS P/A module water recovery scheme). The personnel egress and are flown to land. The vehicle is returned to KSC where it is loaded onto a trailer and taken to a refurbishment facility.

After refurbishment, the vehicle is integrated with a new "service module" and LES. The combined vehicle is lifted atop a new launch vehicle and moved to the launch site.

Impact Attenuation Options - Although water landing was selected as a baseline consistent with the philosophy for this concept, a land landing offers advantages in terms of cost and safety in the out-years of operations. Several landing techniques were explored as alternatives with special emphasis placed on integration issues.

For the deceleration phase of the flight, a lifting parafoil replaced the ballistic parachutes. This is due primarily to range safety concerns, especially for a vehicle without the crossrange capability that would otherwise allow the vehicle to reach latitudes with large uninhabited spaces that would be needed to account for the large dispersions of a ballistic parachute system. As a byproduct of this selection, the impact velocities should be reduced.

In the case of a land landing, the degree of site preparation versus the robustness of the landing system must be traded to produce minimum LCC and maximum safety. The characterization of the landing site will have a significant impact of the preliminary design and conclusions related to competing landing concepts. For this study, a semi-prepared landing "field", level to within 5°, was assumed. Soil bearing strength directly affects the size of the ground contact area. A standardized California Bearing Ratio (CBR) of 7 was selected as typical of this type of site. Actual site soil properties would have to be determined to confirm this selection. A maximum vertical velocity of 13 ft/s and a maximum horizontal velocity of 45 ft/s were used as "worst case" conditions at the moment of impact.

Including any internal landing gear immediately reduces the volume available for the crew and other subsystems. The entire vehicle could, of course, be scaled up to retain a constant volume for the non-landing gear items. Since it was deemed easier to compare configurations of the same size, the internal components were rearranged instead to accommodate the gear. In this case, the "floor" had to be raised about a foot

away from the heat shield. The pressure shell itself becomes more complex, and thus heavier (refer to Figure 20.1-2). Whereas in the baseline configuration, the under floor avionics featured "one layer deep" installation to maximize accessibility, some avionics boxes now had to be installed in layers.

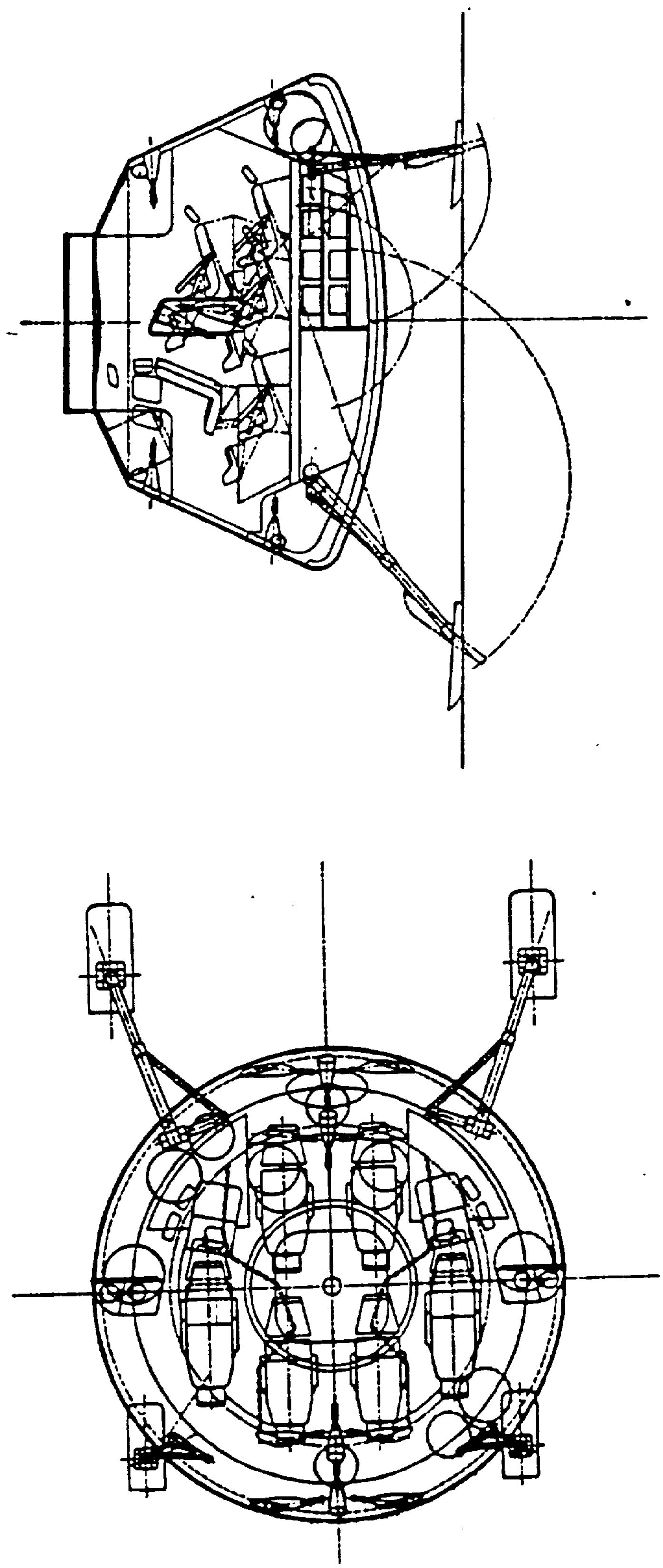
From a flight safety standpoint, the deployable strut concept, or any deployable impact attenuation concept, is less desirable in that there are penetrations in the heat shield. Proper seal design is flight critical to prevent a leakage of hot gas that could destroy the vehicle during reentry. Similarly, to ensure safety, the door/cover for the landing gear might be jettisonable so as to ensure a clean deployment of impact attenuation hardware.

Another impact attenuation option would be to use airbags. In this case, Configuration I is truly amphibious and would be very mission flexible. Initial water landing could be transitioned to land landings. The low center of gravity and wide, relatively flat bottom are well suited to airbags (see Figure 20.1-3). There will be some increase in system complexity and weight, but the pressure shell design is largely unaffected and a variety of landing site conditions could be accommodated.

Launch Vehicle Integration - The "service module" provides most of the physical transition between the launch vehicle diameter and the heat shield diameter. A conical adapter is still likely to be required, depending on the booster diameter. A small forward expendable nose fairing would cover the docking mechanism during ascent.

For continuity with previous study results, the same type of liquid LES, integrated with the OMS propellants, is shown as the baseline. A solid rocket tower, much like Apollo, could provide a simple launch vehicle integration an might be less expensive to develop, although this is only speculative in the absence of any confirmed trade study data.

Downsized Version - For a vehicle designed to carry six personnel (2 pilot-astronauts and 4 SSF crew members) a downsized vehicle is shown in Figure 20.1-4. The 80 inch SSF docking/berthing ring, which integrated easily into the 10 person vehicle becomes a much more significant design constraint in the sizing of a six person vehicle. If this hatch is maintained, the vehicle scaling is significantly affected. As can be seen in Figure 20.1-4, this impact can be seen in the vehicle in the crew cabin height. Although adequate for a seated individual, the ceiling is somewhat short for a



Side View

Top View

Figure 20.1-2. Configuration I Land Lander with Struts

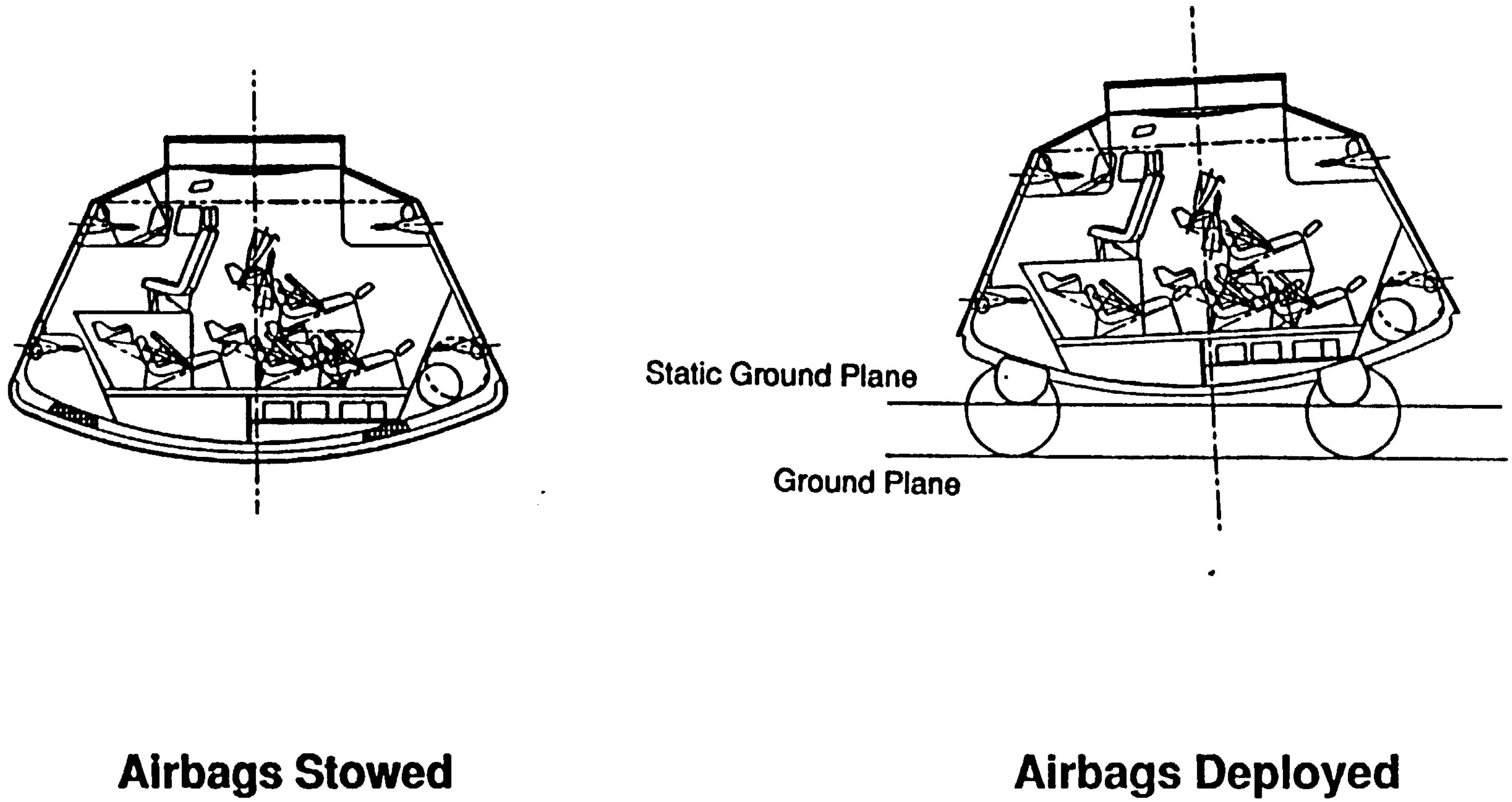


Figure 20.1-3. Configuration I Land Lander with Airbags

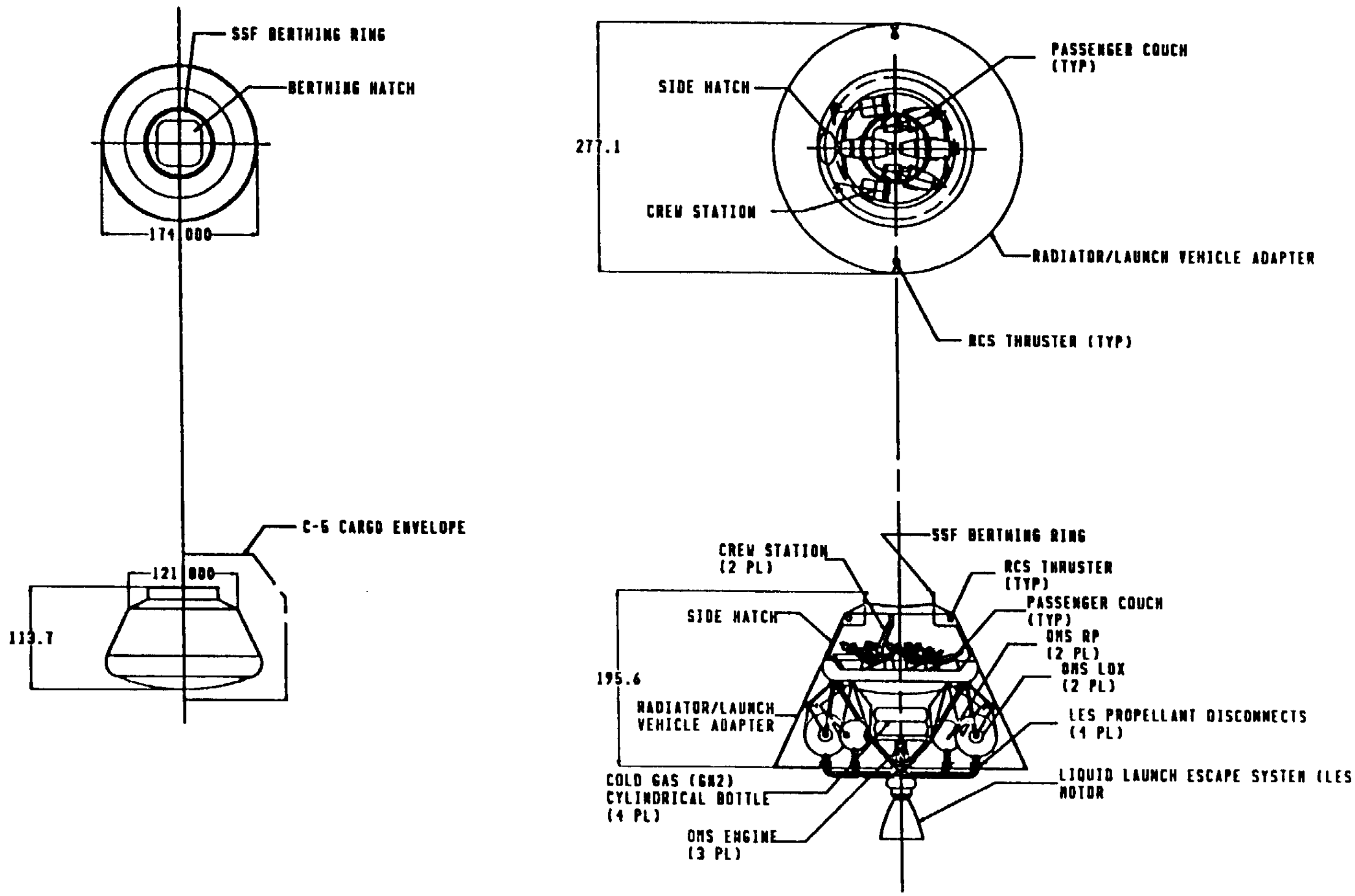


Figure 20.1-4. Configuration I General Arrangement (6 Person)

standing person. If the PLS hatch was limited to a 40 inch opening , the hatch diameter would no longer drive the vehicle design and would allow the vehicle to be sized to provide for sufficient cabin height.

20.2 Configuration II

This configuration features a mid L/D concept that offers good reentry performance while still retaining the advantages of a simple, efficient shape. The biconic shape as described in the previous study reporting was used as the baseline for Configuration II (see Figure 20.2-1). Because it was discussed previously, only the alternative configuration options that were examined are discussed here.

Impact Attenuation Options - As was the case in Configuration I, a primary issue relating to land landing involves the characterization of the landing site terrain. Even with a controllable parafoil recovery device, a paved area of the size required for all possible landing conditions would be expensive to build and maintain. An airbag landing option is shown as Figure 20.2-2.

Downsized Version - A six person version of Configuration II is shown as Figure 20.2-3 Important to note in this figure is the fact that on this downsized vehicle (as is the case also with Configuration I) the limiting factor in the vehicle size is the pressurized volume itself. With the OMS and radiator in a separate module, these items place no constraints on vehicle size. With this modularity, the vehicle need not be much larger than the pressure vessel itself.

20.3 Configuration III

As discussed in the concept philosophy, Configuration III is a lifting body design that maximizes hypersonic performance and volumetric efficiency. Lifting bodies can be shaped in many ways but all can be characterized as low fineness ratio shapes that fly at moderate to high angles of attack to present a blunt shape to the direction of flight.

Concept Description - The selected lifting body configuration is shown in three views as Figure 20.3-1. As a baseline, the vehicle lands on a runway with a tricycle landing gear. Integration of a thermal radiator with this vehicle is, as was the case in Configurations I and II, complicated by the fact that the required radiator area is nearly as large as the entire wetted area of the vehicle. In the case of Configurations I and II, this problem is alleviated with the disposable OMS/radiator/launch vehicle adapter. In

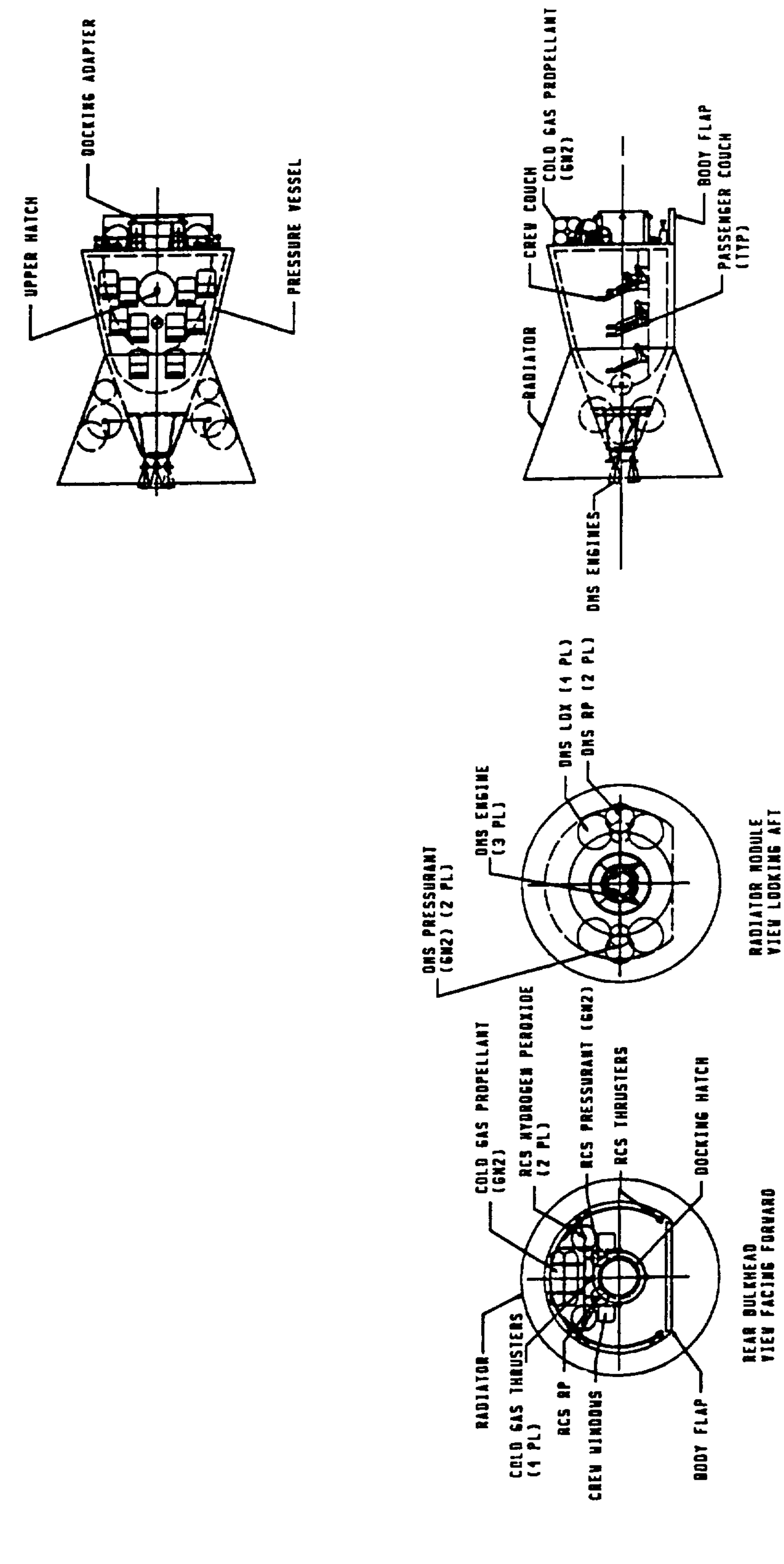


Figure 20.2-1. Configuration II General Arrangement (10 Person)

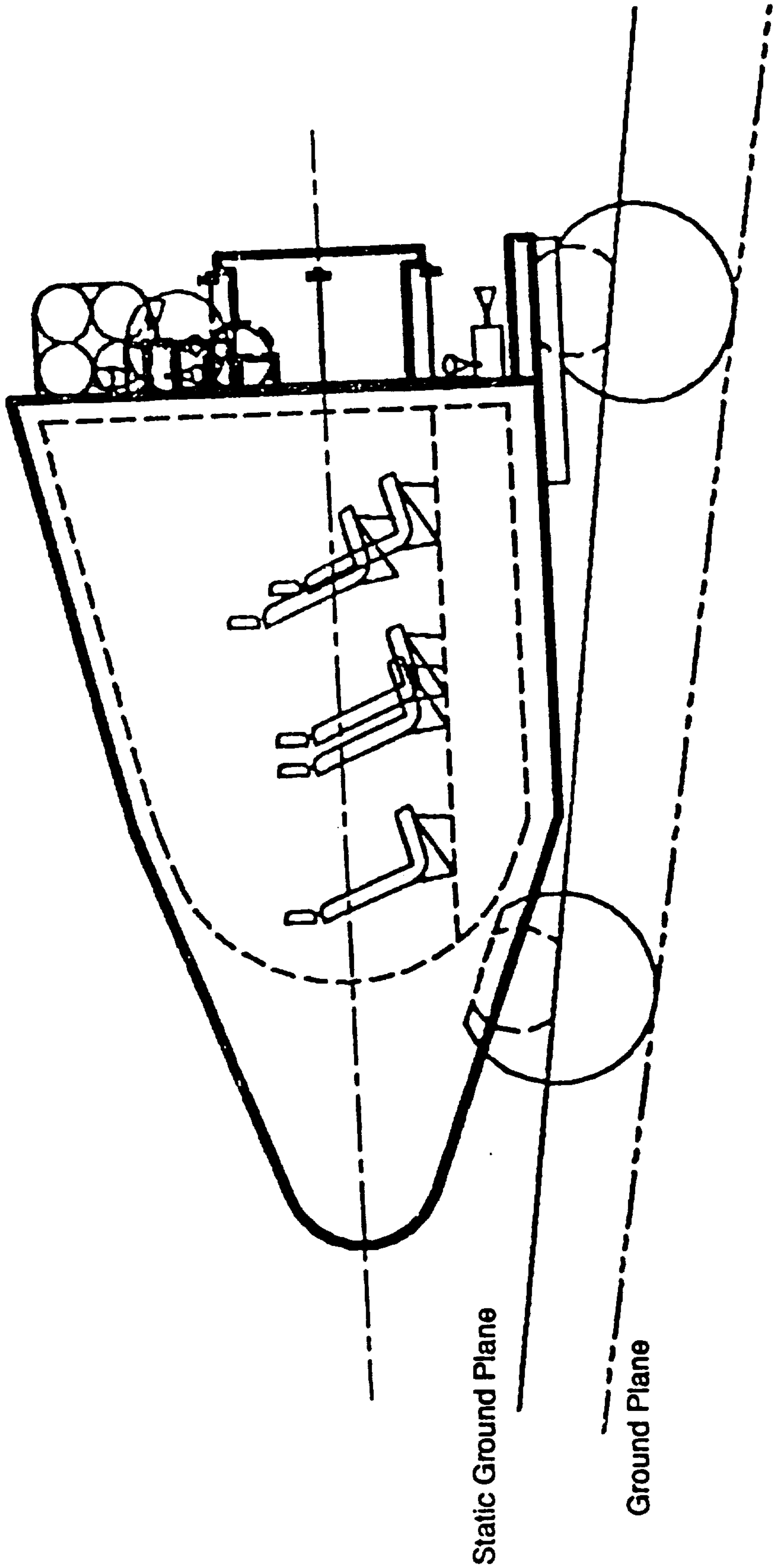


Figure 20.2-2. Configuration II Airbag Landing Option

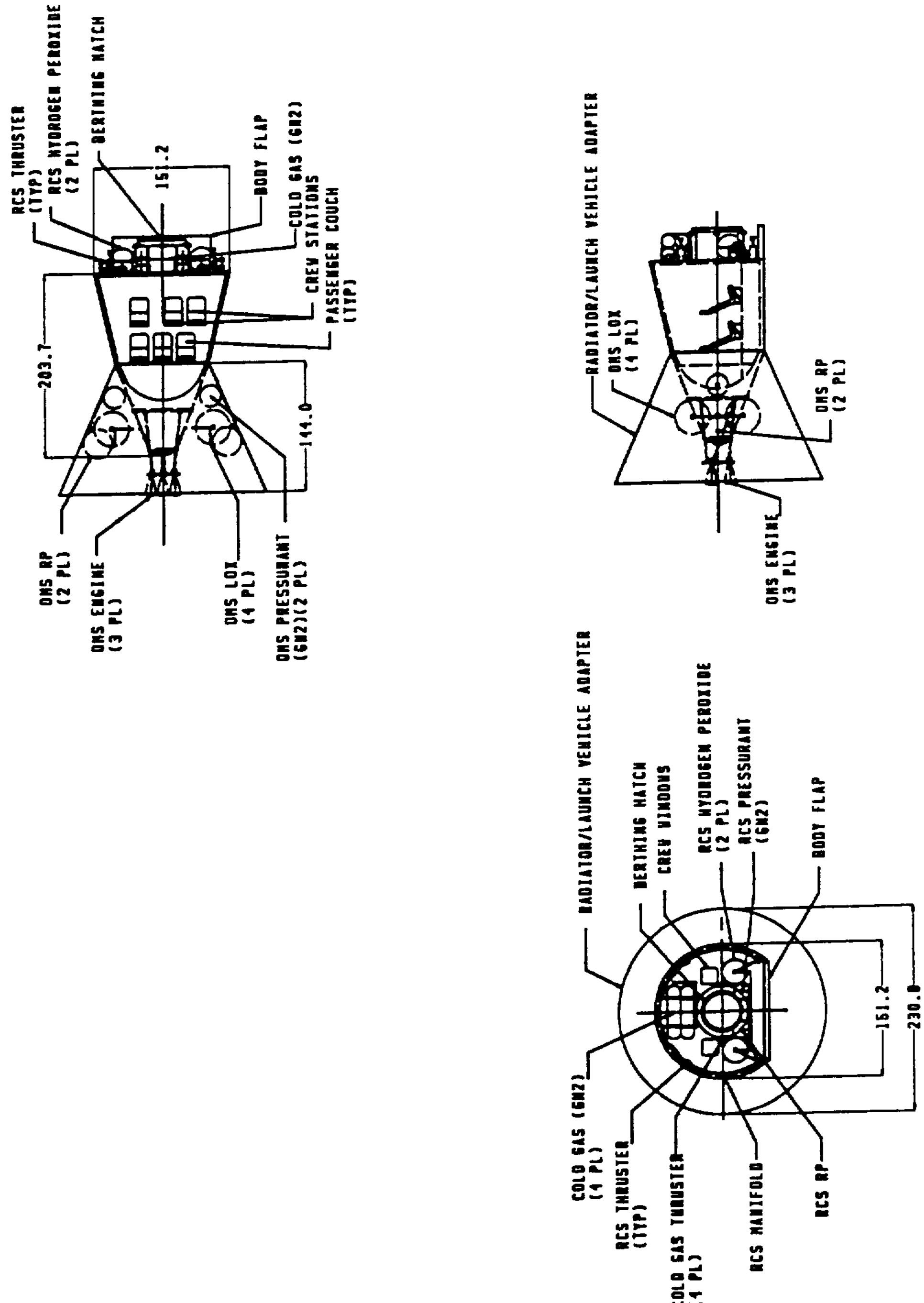


Figure 20.2-3. Configuration II General Arrangement (6 Person)

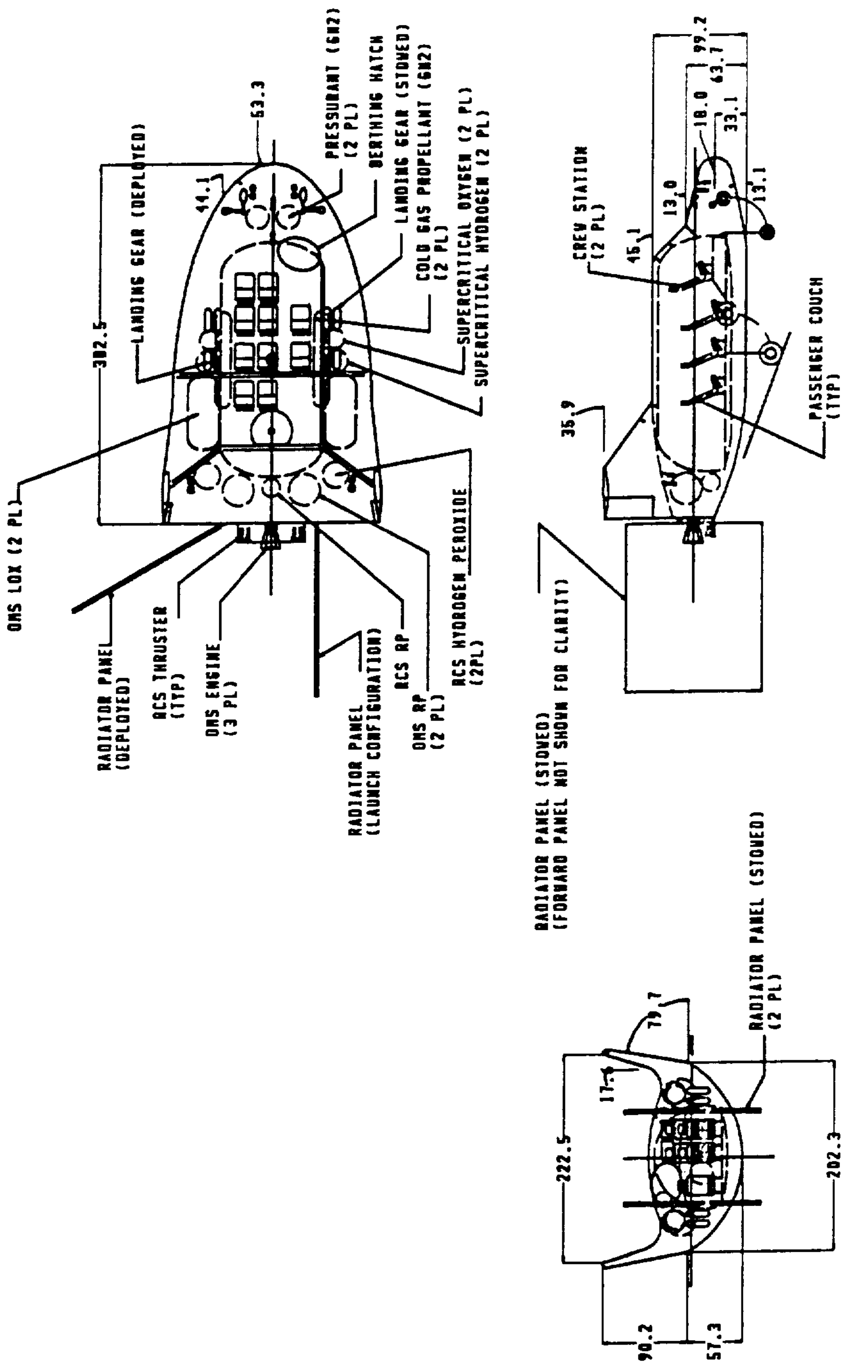


Figure 20.3-1. Configuration III General Arrangement (10 Person)

the case of Configuration III, however, the location of the OMS engines further complicate the issue. The OMS engines, located against the aft bulkhead (where they are protected for the aerothermal environment of reentry) would heat the inside of a radiator/launch vehicle adapter module. If such a heat rejection device were used, the inner surface of the radiator would have to be insulated to reduce the heat input to the cooling system during engine firings. This insulation would translate into additional system mass. One means of alleviating this heat load and subsequent insulation addition, would be a pair of radiator panels attached to the aft bulkhead as is shown in Figure 20.3-2. This radiator panels would be stowed inside the launch adapter during the ascent phase of the mission and would deploy outward (like a pair of butterfly wings) following launch vehicle separation. These radiator panels will remain deployed throughout the orbital phase of the mission and like the launch vehicle adapter radiator module, would be jettisoned just prior to vehicle reentry. Although this system is not able to take advantage of the launch vehicle adapter to the same extent as Configurations I and II, this fold out radiator does not have the additional insulation required to reduce the heat input to the coolant loop.

The exterior design of Configuration III is intended to represent a typical example of a lifting body based on a half cone theoretical body. Large vertical fin surfaces are required to counter the poorly damped roll-yaw characteristics of these types of vehicles. The blunt base region is used to attach to the launch vehicle. In addition, the recoverable OMS engines are located on the aft end - protected from the heat of reentry, but exposed for radiative cooling during firings.

One interesting discovery relating to these shapes was that it was very difficult to achieve packing density similar to the other concepts - in other words, Configuration III had excess internal volume. Although the shape is volumetrically efficient, the cross section was driven by the anthropomorphic requirements of the crew. The side areas outboard of the pressure shell tend to have much more volume than is required, even with the internalization of OMS tankage.

There are several possible locations for the docking port. One location would be on the base area at the aft end of the vehicle. On the positive side, this arrangement would allow mission unique hardware, such as an airlock or satellite servicer to be attached under a launch shroud/interstage. There are several disadvantages of an aft docking port:

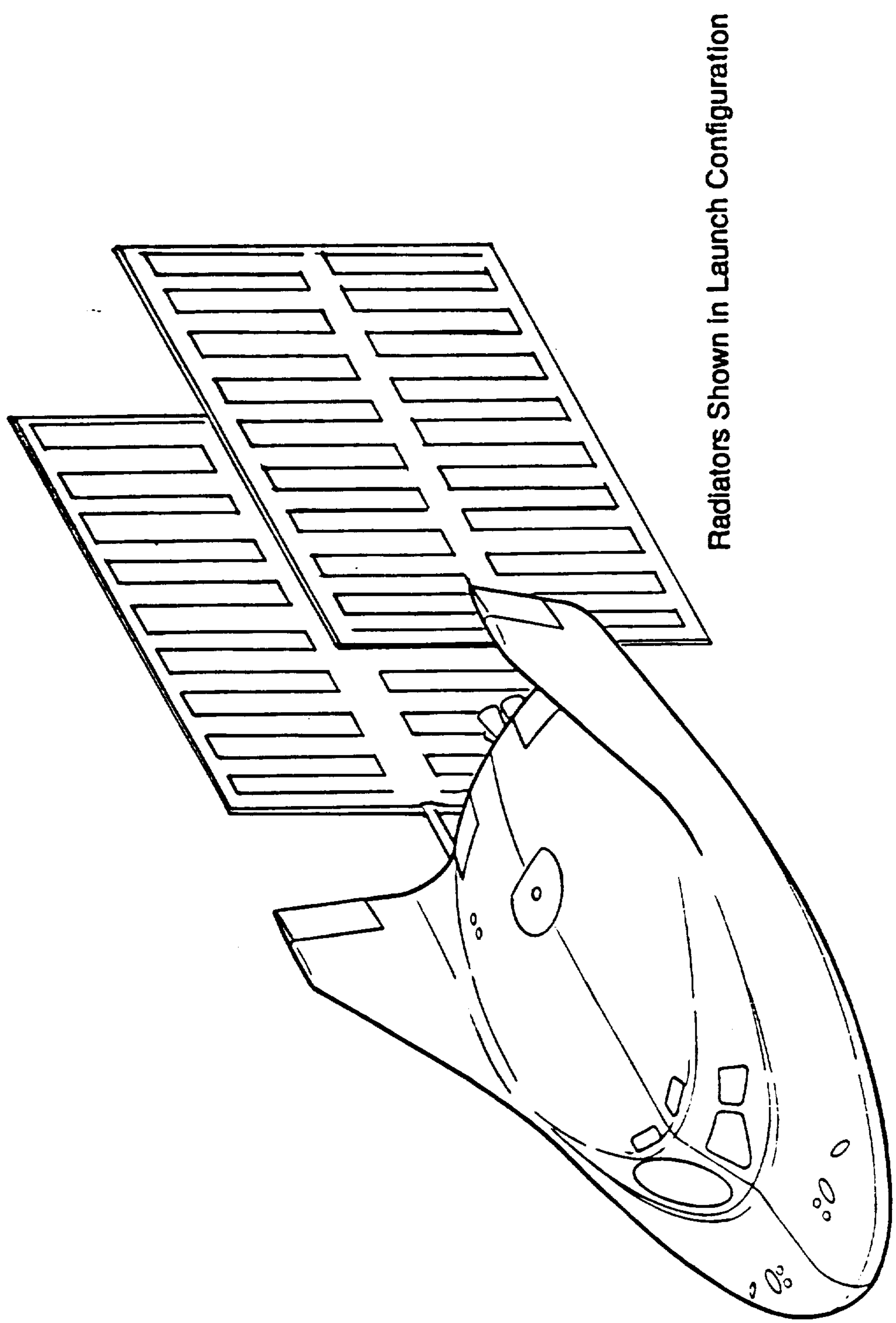


Figure 20.3-2. Radiator Arrangement for Configuration III

- The OMS engines fire in the direction of any docking maneuver and/or are physically vulnerable to contact during rendezvous,
- any piloted docking functions would involve a second set of controls and displays and would require a pilot to move past the rest of the passengers (in a tight cabin) to reach the aft end, and,
- the base area/boattail angle would increase, thus decreasing subsonic landing performance.

Another location for the docking port would be on top of the vehicle. This location should be aerodynamically protected. This location would tend to negate the possibility of a second ingress hatch (good for weight, but safety concerns may not allow this).

Another unique possibility, shown on the baseline Configuration III, would be to locate the docking port on one side of the forward end of the pressure shell. Because the configuration is relatively wide, such an arrangement would enable the pilots to have visibility and use controls/displays that would require no relocation. A protective cover to ensure reusability of docking hardware would be required.

Operational Description - One difference between Configurations I and II, and III and IV is the latters' ability to "fly" an abort trajectory that might allow the vehicle to return to the launch site, or land somewhere other than the ocean. Section 4.4 will discuss these aborts in more detail. Otherwise, the launch, orbital insertion and rendezvous phases of Configuration III are nearly identical to those procedures described for Configurations I and II. The primary configuration difference is that the PLS would separate from the interstage after launch vehicle burnout. The baseline features an expendable set of radiator panels, protected during ascent in the interstage and then folded out, like a butterfly, before the OMS is fired.

After the orbital mission is complete, the OMS is fired to begin the descent from orbit. After the deorbit burn, the radiator panels are jettisoned, and the RCS turns the vehicle around to orient the vehicle "nose first" for reentry. A lifting trajectory with bank modulation for crossrange and heating control is flown. The vehicle flies to an airfield, flairs, and lands on a runway. The passengers can egress from the vehicle soon thereafter.

The vehicle is towed to a refurbishment facility, where new radiators and LES are attached. The vehicle is transported the the launch vehicle facility, where it is raised "nose up" and integrated onto a launch vehicle.

Impact Attenuation Options - One disadvantage of the runway landing lifting body involves the high touchdown speeds and short decision times, especially in a piloted (backup mode) landing. While the lifting body has good hypersonic performance, the subsonic characteristics are typically marginal. An alternative might be to fly the vehicle hypersonically/supersonically to the landing zone and then to deploy a parachute or parafoil to slow the vehicle to a vertical landing. This technique has been used for a variety of military drones. Since the vehicle must carry some form of parachute for water abort landings anyway, it was felt that this would not require any additional system hardware. The issue of impact attenuation remains, however, to address the terminal deceleration after touchdown with the ground.

Deployable struts, similar to the baseline landing gear but without wheels and brakes could be used. Airbags are another alternative that would work well on the bottom of this flat bottomed, low center of gravity concept.

Launch Vehicle Integration - The PLS sits atop the launch vehicle with no forward shroud. A tapered adapter between the LV and the PLS aft end will not be axisymmetric, as was the case in the previous configurations. The LES engine is shown as a liquid motor using OMS propellants as before. However, since the OMS tankage is internal to the lifting body in this arrangement, separation of the larger LES plumbing lines would be more complex than that in Configuration I or II. Several solid motors mounted on the interstage would be a simpler, if heavier, alternative.

Downsized Version - A six person version of Configuration III is shown as Figure 20.3-3 Unlike Configurations I and II, downsizing this vehicle is complicated by the fact that, in staying with the operational philosophy of reduced operations costs, carries all propellant tankage (both OMS and RCS) internally. Although there are small changes in the amount of propellant carried in going from the 10 person vehicle to the 6 person vehicle, these propellant tanks are essentially the same size in the downsized vehicle as in the full size vehicle. For this reason, unlike the vehicles which carry their fuel externally (i.e. Configurations I and II), the amount the vehicle can shrink is

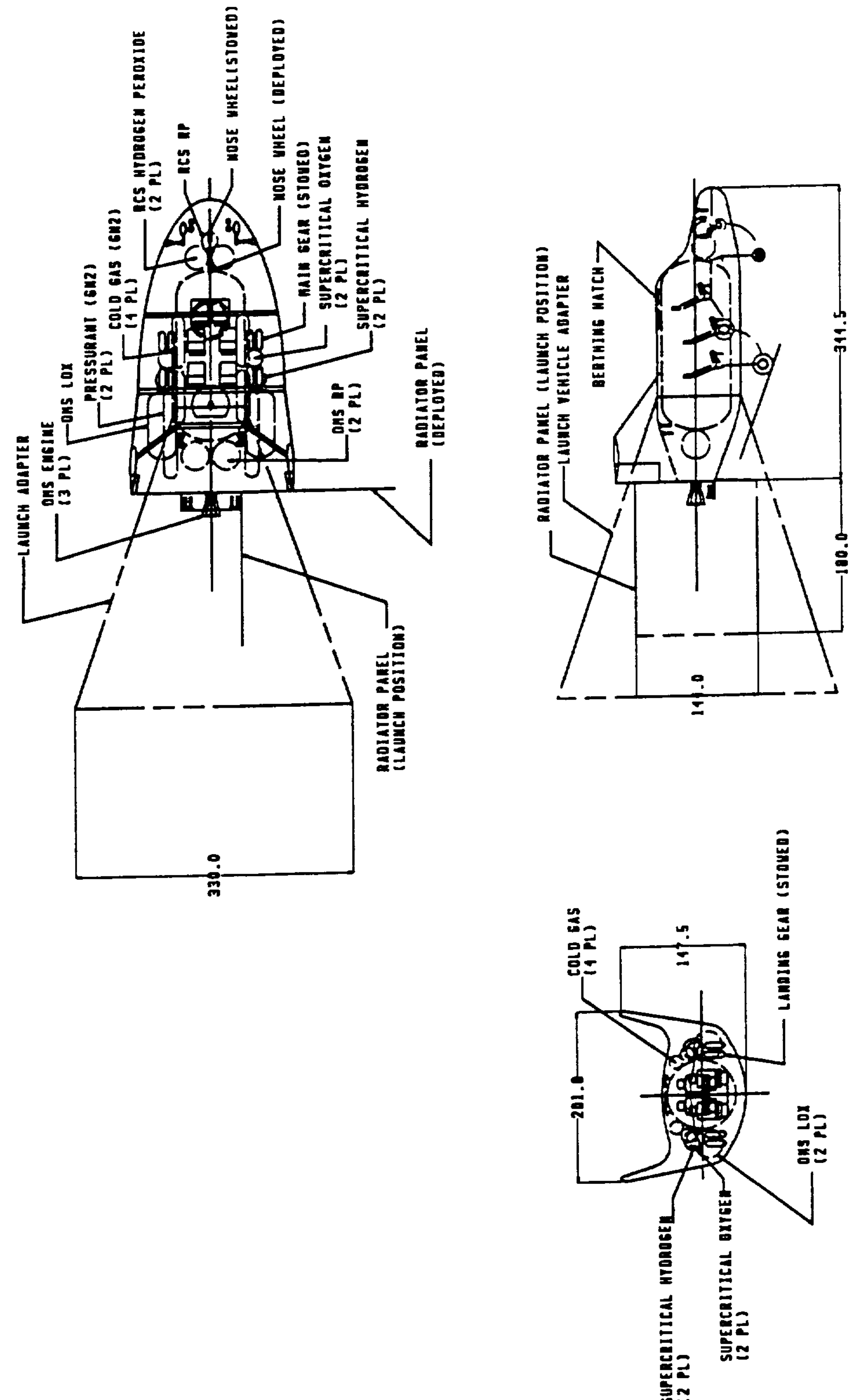


Figure 20.3-3. Configuration III General Arrangement (6 Person)

constrained not only by the pressure vessel of the vehicle but also by the propellant tankage.

While the configuration is limited during the downsizing by the pressure vessel and the tankage, the pressure vessel is limited in its size by the personnel themselves. In the 10 person version, the vehicle height is already set by the crew cabin height. When the crew load is reduced, this height was held constant to maintain similar crew accommodations. This means that although the pressure vessel can get narrower, it cannot get shorter, the impact of this is significant in the highly integrated, blended shape of the lifting body configuration.

Because of the constraints place on the downsized design by the tankage and the crew volume (or more accurately, height) the amount that Configuration III changes with the downsized passenger load is much less than would be expected.

20.4 Configuration IV

Concept Description - On the opposite end of the spectrum from Configuration I, Configuration IV is designed to be a vehicle whose configuration is dictated by the desire to reduce operational costs to as low a level as possible.

To this end, the overall vehicle is configured to achieve the best possible subsonic performance and handling even at the expense of hypersonic performance and handling. This desire to improve the subsonic characteristics is driven by the desire to reduce vehicle landing speeds to those normally experienced by current high performance aircraft (~175 knots). A vehicle capable of landing at these speeds has the increased operational flexibility of being able to use a larger number of airfields throughout the world.

In some ways, the outer mold line of Configuration IVA (see Figure 20.4-1) is similar to that of the Space Shuttle Orbiter in that it has a flat sided fuselage with a rounded top. In both vehicles, the crew is seated over the nose of the spacecraft to allow them good visibility over the nose during the atmospheric flight phase.

Unlike the Orbiter, Configuration IV's low mounted wing is a simple delta shape with large tip fins for lateral control. These tip fins are sized not only to provide hypersonic stability and control but also to allow the vehicle enough control to be able land the vehicle in a 22 knot crosswind.

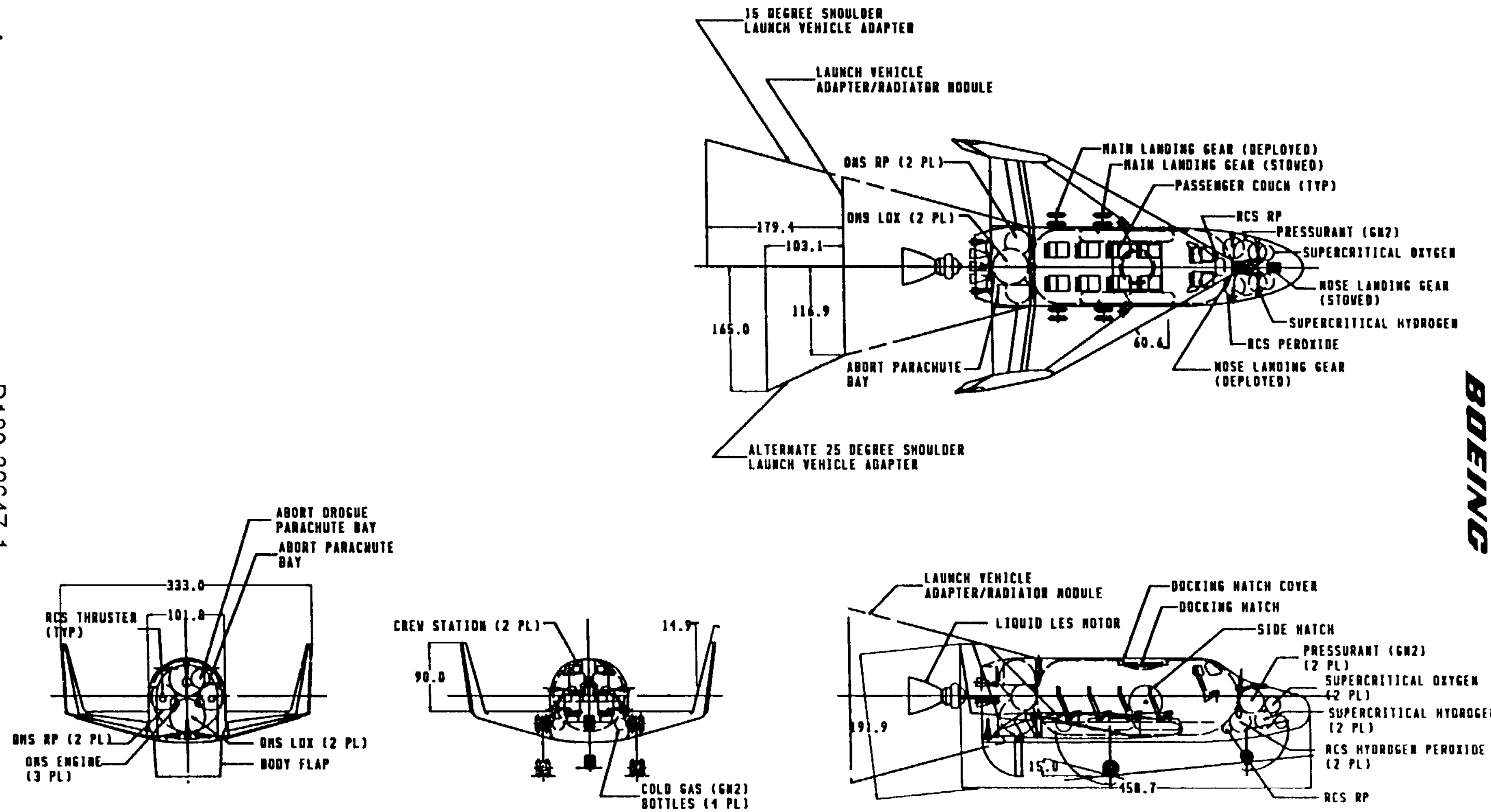


Figure 20.4-1. Configuration IVA General Arrangement (10 Person)

Beside the wing shown in Figure 20.4-1, two additional wing sizes were considered to assess the vehicle impacts of changing the thermal protection system (TPS) of the vehicle.

Because Configuration IV is a vehicle designed for minimum operations costs, the high operational costs associated with the current ceramic tile TPS used on the Orbiter were considered a good candidate for elimination from Configuration IV. The ideal TPS for an operational vehicle is an all metal system similar to that which was envisioned for earlier studies, such as the X-20 DynaSoar and the RASV. Composed of very high temperature metal alloys such as Inconel with an eye towards incorporating as much NASP material technology as possible, this is a very robust system which would go far towards the goal of reducing the vehicle operations costs.

From the vehicle studies mentioned, it was felt that the maximum wing loading (i.e. landing weight/wing area) that the vehicle could have and still keep the aerothermal loads sufficiently low enough to allow metallic TPS was 22 psf. It was this low wing loading which led to Configuration IVB, the vehicle shown in Figure 20.4-2. As is quite apparent from this figure, an all metal TPS vehicle in this weight class is quite unwieldy and in fact the possibility exists that the size of the vehicle and the awkwardness of its handling will create more additional operations costs than the metallic TPS will eliminate.

As an attempt to find a compromise between the 75 psf wing loading and ceramic TPS of the Configuration IVA and the unwieldy Configuration IVB with its all metallic TPS, a third configuration was developed. Remembering that the maximum heating rate (and hence maximum temperature) of the reentry is a function of ballistic coefficient (ie. wing loading) this third configuration, Configuration IVC, will split the difference between Configuration IVA and IVB and was designed with a wing loading of 45 psf (see Figure 20.4-3). Although to hot to allow the TPS to be entirely metallic, this moderate wing loading should allow the use of carbon/carbon leading edges (perhaps as far back as the front wing spar) with the majority of the vehicle being made of the high temperature alloys mentioned earlier, again making as much use as possible of NASP material advances.

In keeping with the operation philosophy of minimizing operational costs, Configuration IV was designed with the goal of completely eliminating the use of

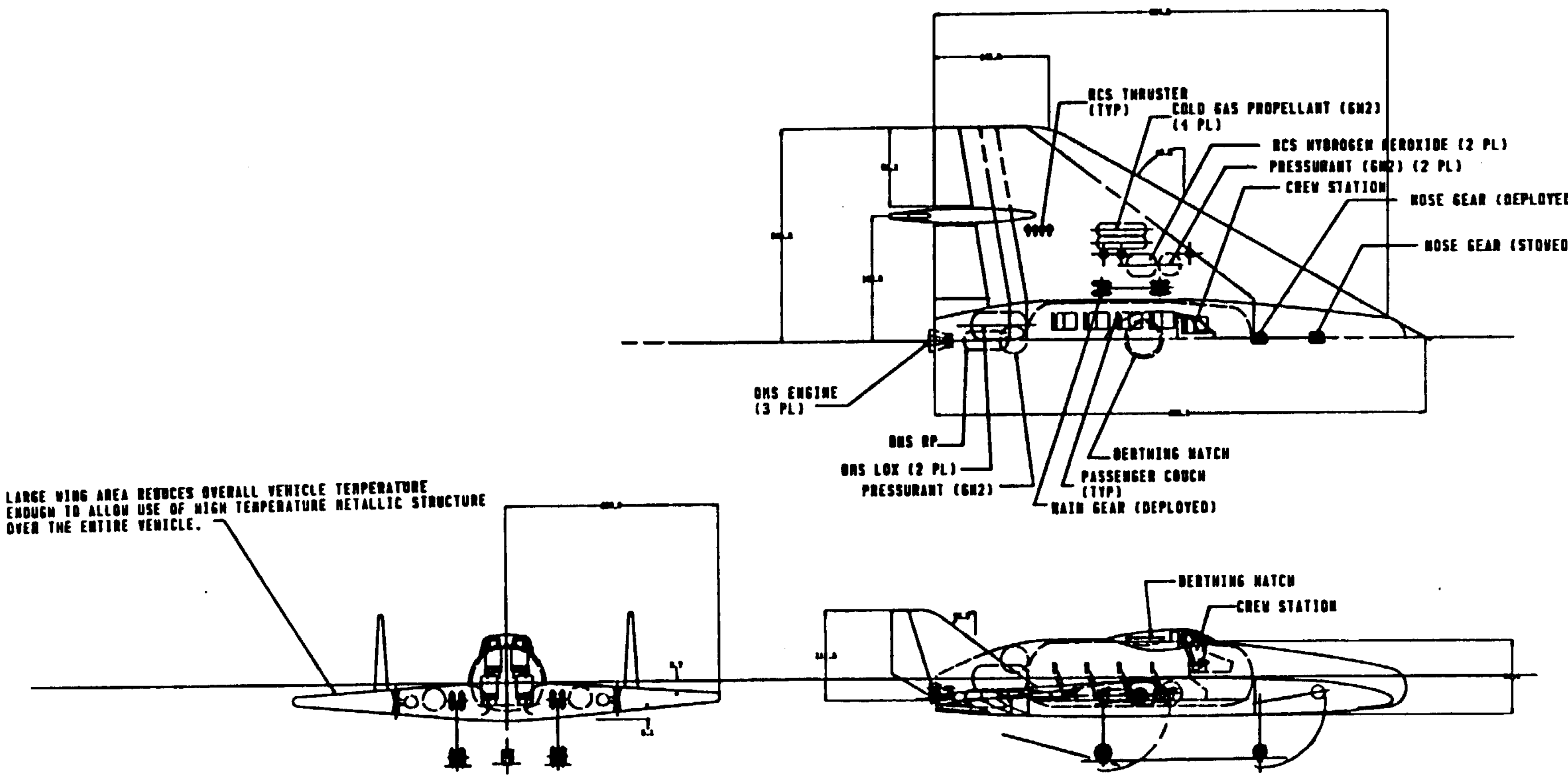


Figure 20.4-2. Configuration IVB General Arrangement (10 Person)

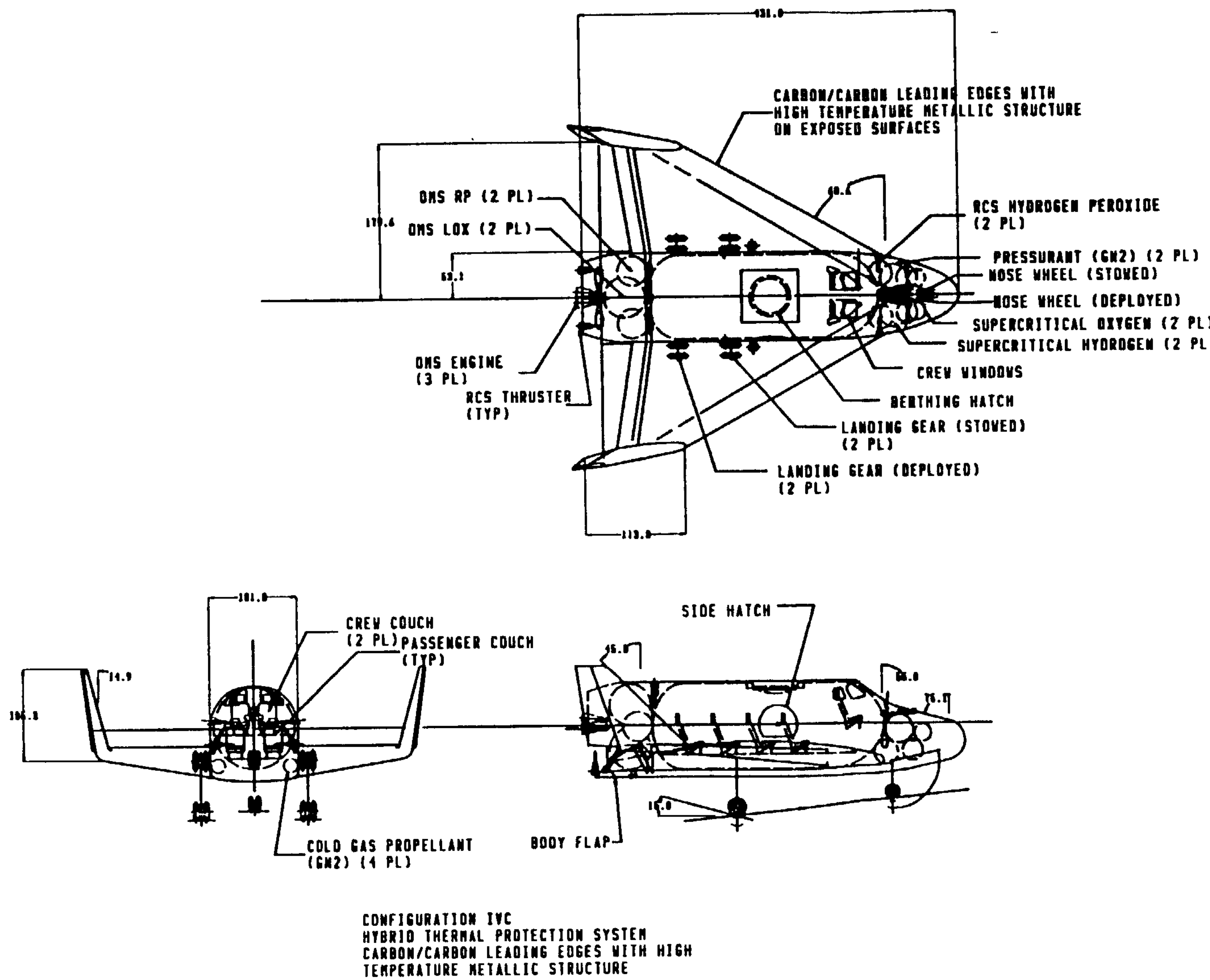


Figure 20.4-3. Configuration IVC General Arrangement (10 Person)

expendable hardware, or in essence, how could the radiator be brought back to the ground. Because the radiator is such a large piece of hardware on all the PLS vehicles (assuming typical rejection capacities of 15 W/ft^2) the first three configuration classes (I,II, and III) would have a very difficult time providing protection for a radiator during the reentry and hypersonic flight phases of the mission. For this reason, in all three of those configurations, just prior to reentry, the radiator is discarded and the vehicles rely on boilers to provide system cooling.

In Configuration IV, this expendable radiator was felt to be out of step with the operational philosophy of minimizing operations costs. Two different possibilities arose about how these radiators could be kept and protected during reentry. The first of these is shown in Figure 20.4-4 and consists of an accordion fold radiator which would stow in a large bay in the nose of the vehicle. This radiator would be deployed for orbital ops and then be stowed prior to reentry. Should the radiator fail to stow it would have to be jettisioned. The second radiator concept considered is a much less complex and safer concept than the stowable one however, it does not work on the smaller wing of Configuration IVA. In this concept, the wing itself is used as the radiator as shown in Figure 20.4-5. This concept is only viable on the metallic winged vehicles for two reasons. First, only the metallic winged vehicles have enough surface area to provide adequate radiators and second, because ceramic TPS is a good insulator, any vehicle with ceramic TPS cannot create enough ΔT across the TPS to radiate the required amount of heat.

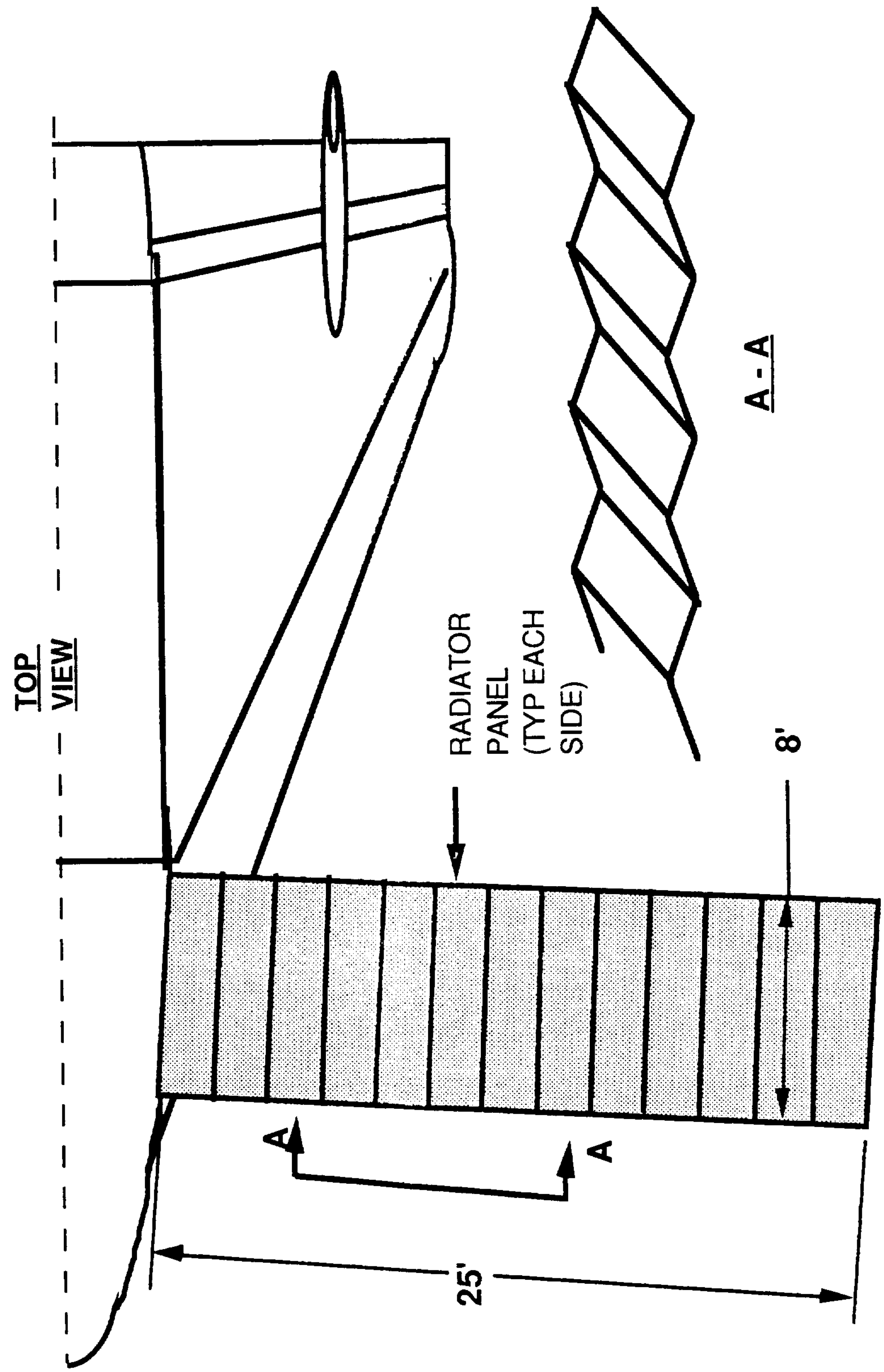


Figure 20.4-4. Alternative Folded Radiator Concept

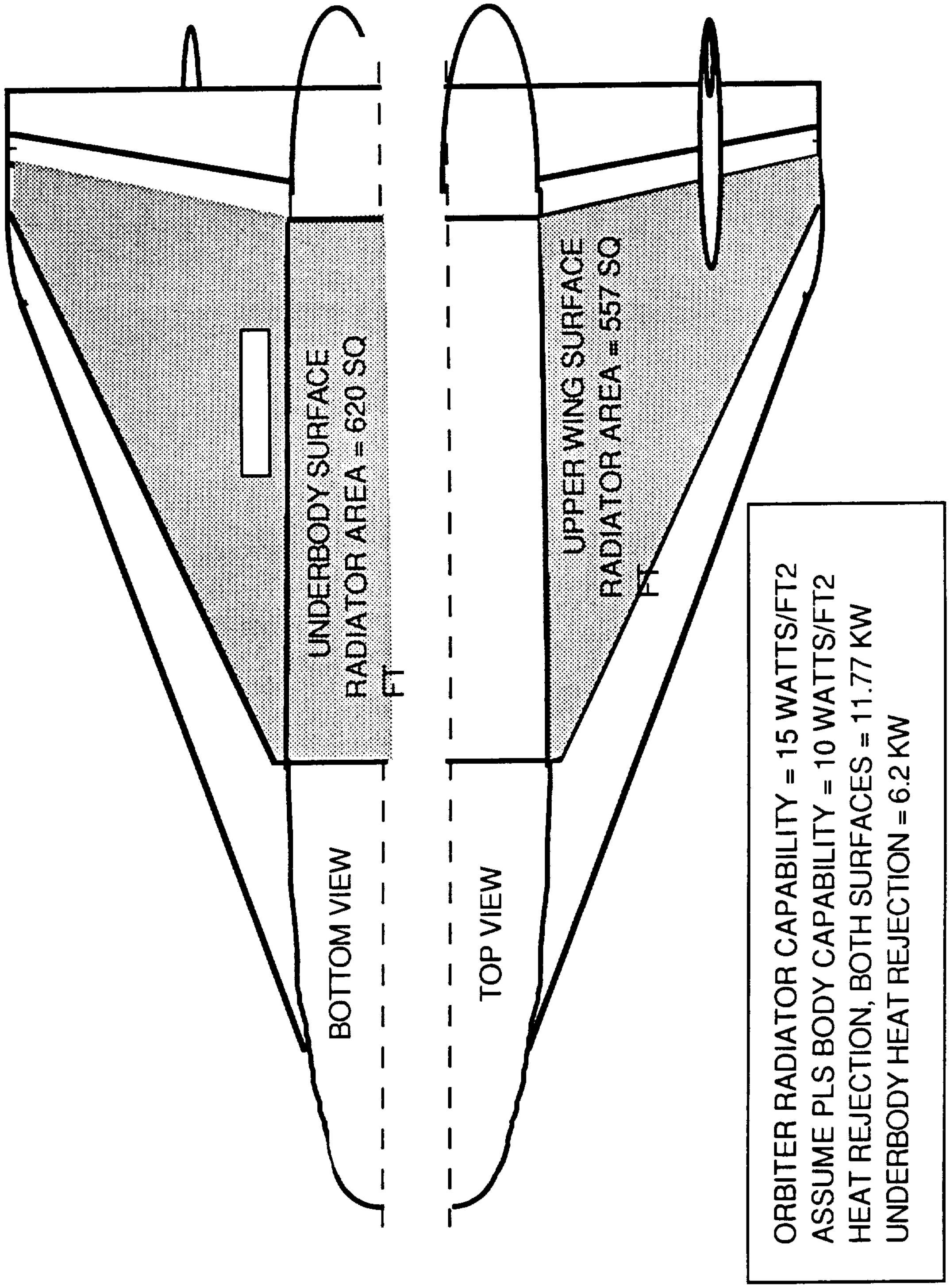


Figure 20.4-5. Alternative Integral Radiator Concept

Operational Description - Building on the operational concepts described for the other concepts, Configuration IV includes many of the same flight phases.

One major difference between Configuration IV and the other concepts is the absence of any expendable hardware (not including the launch vehicle adapter and LES). The OMS is carried onboard, as is the radiator.

Reentry is concluded by a runway landing at moderate speeds. Careful subsystem selection will have eliminated the toxic hazards that would prevent the passengers from immediately egressing after the vehicle comes to a stop.

Launch Vehicle Integration - As was the case in Configuration III, a more complex (non-axisymmetric) shape for the interstage will be required. Again, a simpler alternative to the OMS/LES combination shown on Configuration II would be to use a set of solid motors attached to the interstage.

Downsized Version - A six person version of Configuration IV is shown as Figure 20.4-6 Important to note is that in this vehicle, like Configuration III, the propellant tankage and the passenger cabin height again combine to keep the reduction in passenger load form changing the overall configuration very dramatically.

On top of this difficulty of changing the body size, the wing of Configuration IV is also constrained by the vehicle weight (because of wing loading effects on landing and aero heating) and in the case of the metal wings, radiator area. All of these items conspire to prevent Configuration IV (A, B or C) from scaling much at all.

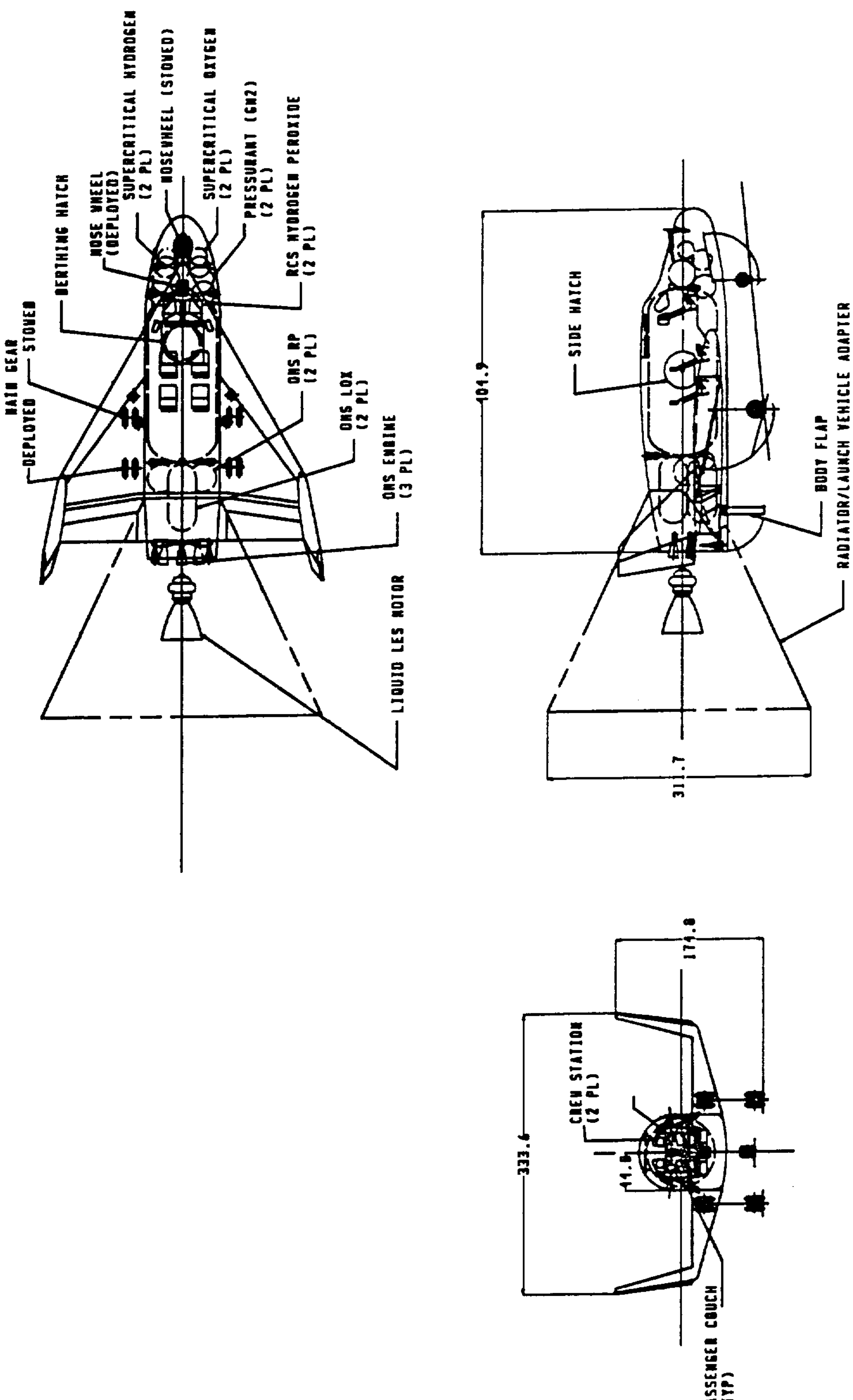


Figure 20.4-6. Configuration IV General Arrangement (6 Person)

21 CONCEPT ANALYSIS

21.1 Aerodynamics

Subsonic and hypersonic aerodynamic characteristics were developed for the PLS entry configurations for initial performance and controls analysis. The aerodynamics are based on empirical methods from Missile Datcom, Airez and APAS aerodynamic codes.

The vehicle definitions used for this analysis are shown in Section 3. Hypersonic control effectiveness was determined for five flap settings including -30°, -20°, -10°, 0°, and 10° (positive deflections are trailing edge down). The moment reference center (MRC), was selected to allow the configuration to trim in the angle of attack range for the maximum lift-to-drag condition to the maximum lift condition (20° to 40° angle of attack). The data for pitching moment versus angle of attack and control deflection and stability plots, normal force versus pitching moment are shown in Figures 21.1-1 to 21.1-8. The MRC, i.e. reference center of gravity position, is shown on each figure. Trim capability is comparable for the lifting body, biconic and wing-body configurations. However, the biconic and wing-body trim at a further aft center of gravity location than the lifting body. The wing-body offers more flexibility in center of gravity location since the wing location and aerodynamic shape can be more easily tailored and does not involve repackaging the configuration. The lifting body was configured with elevons the same size as the wing-body elevon and with elevons 60% smaller. The data indicate the smaller elevon is effective and adequate for the more forward center of gravity location.

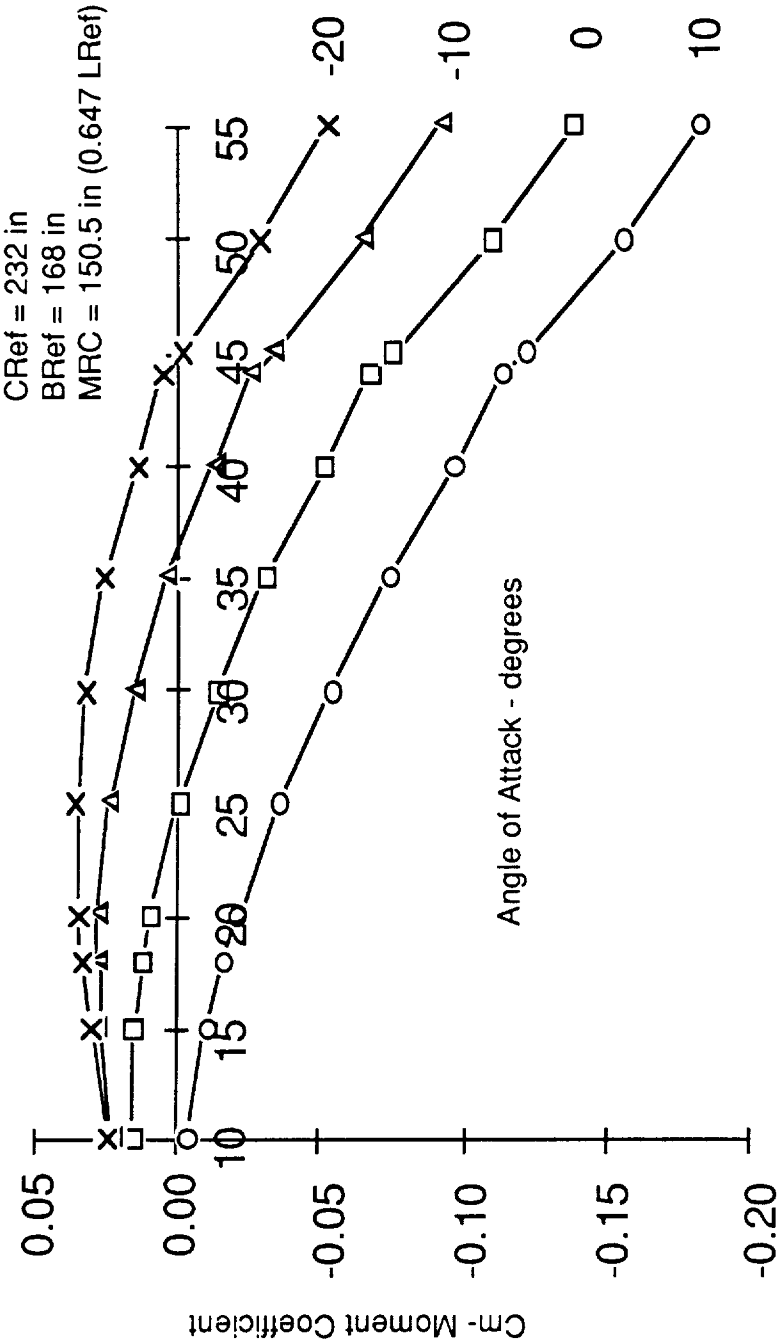


Figure 21.1-1. Configuration II - Hypersonic Flap Effectiveness

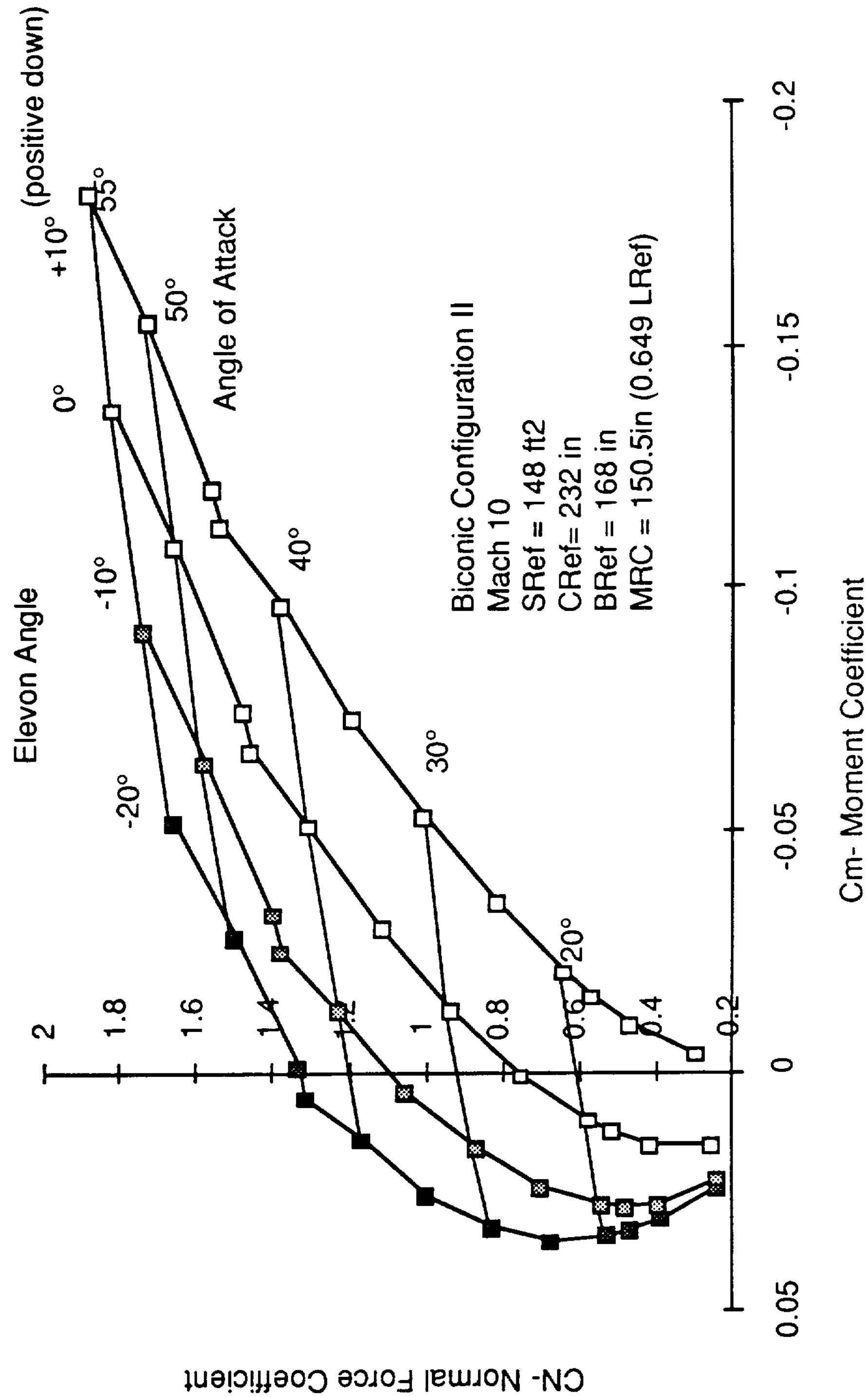


Figure 21.1-2. Configuration II - Hypersonic Stability Characteristics

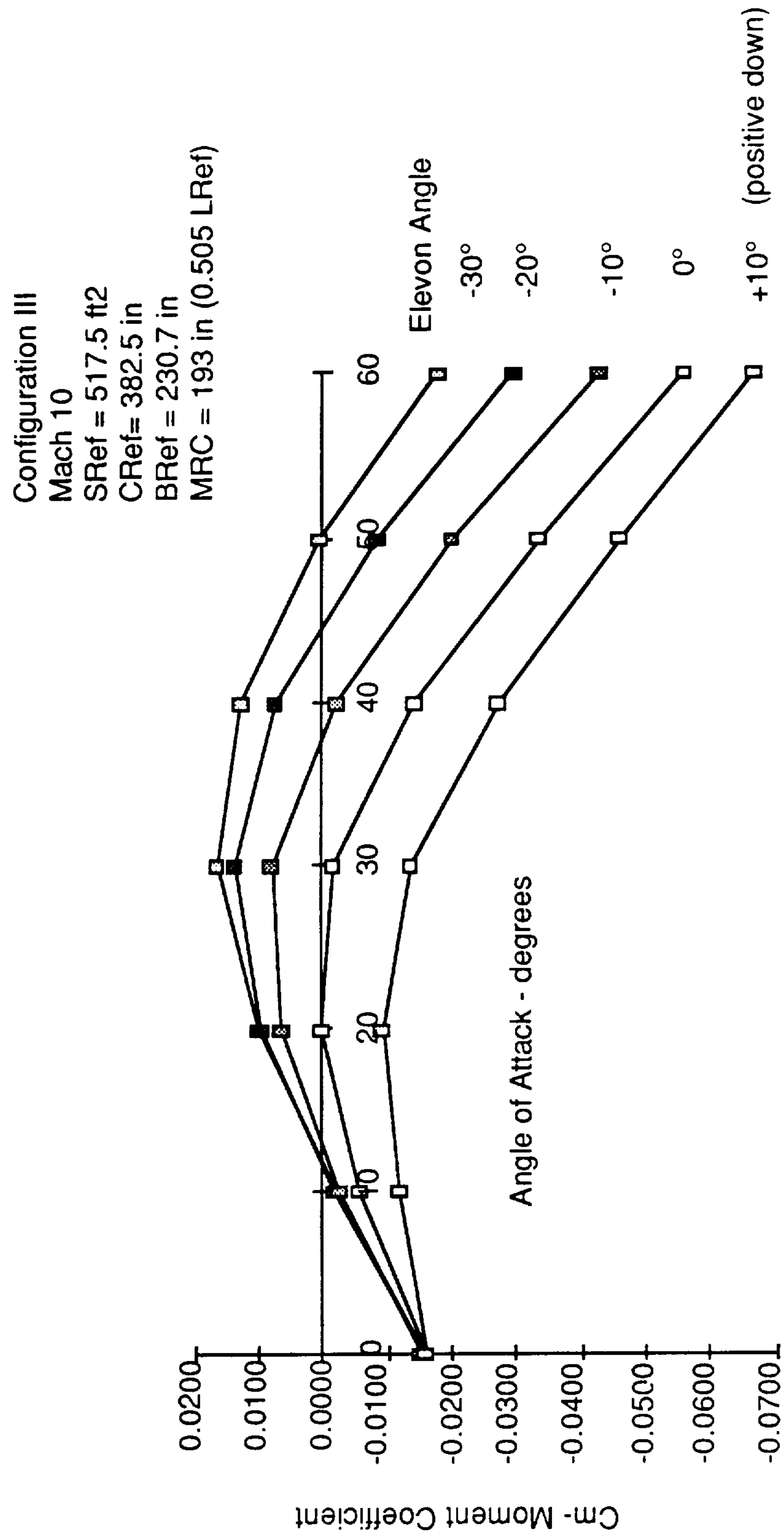


Figure 21.1-3. Configuration III - Hypersonic Elevon Effectiveness

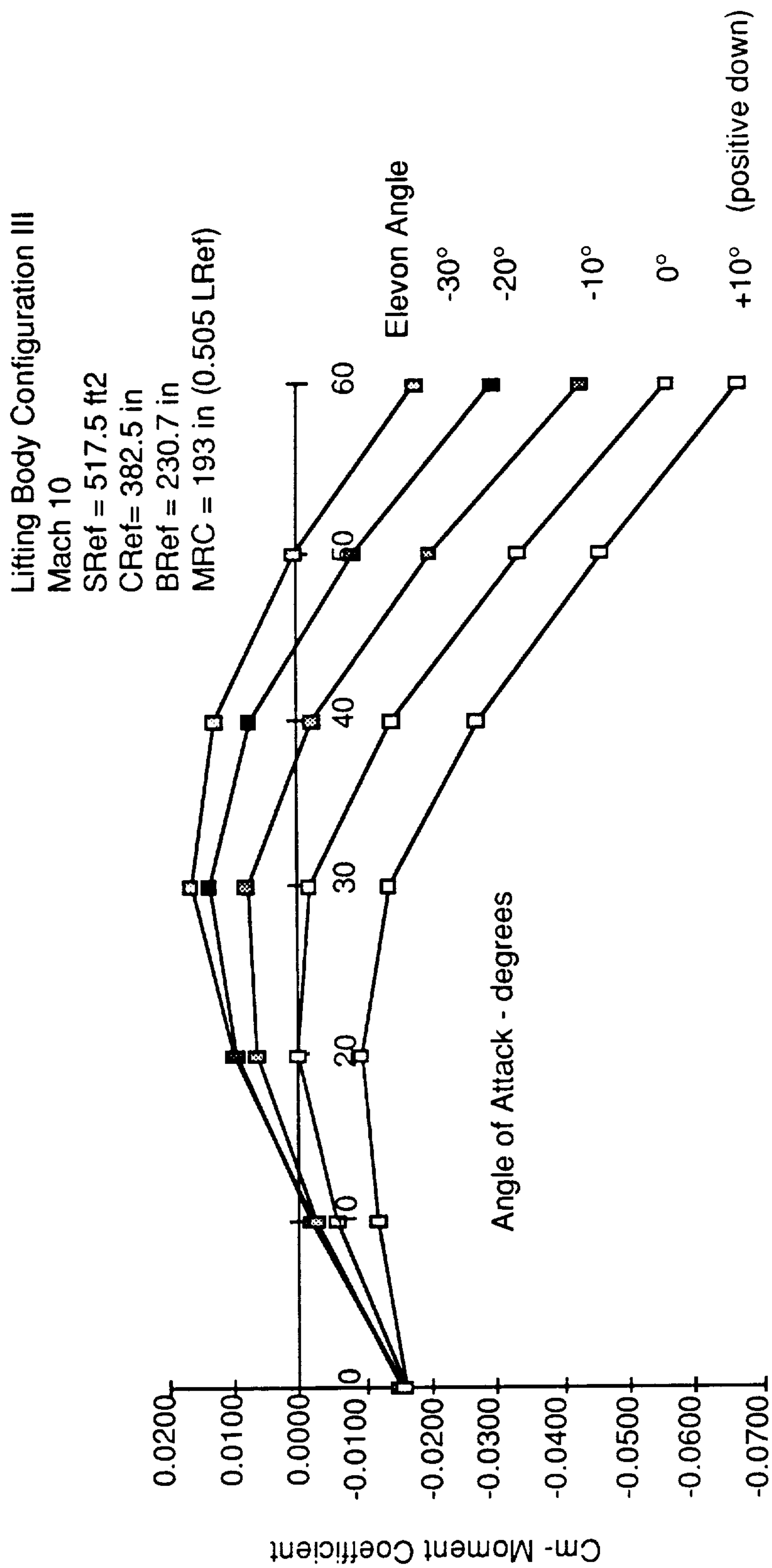


Figure 21.1-4. Configuration III - Hypersonic Elevon Effectiveness

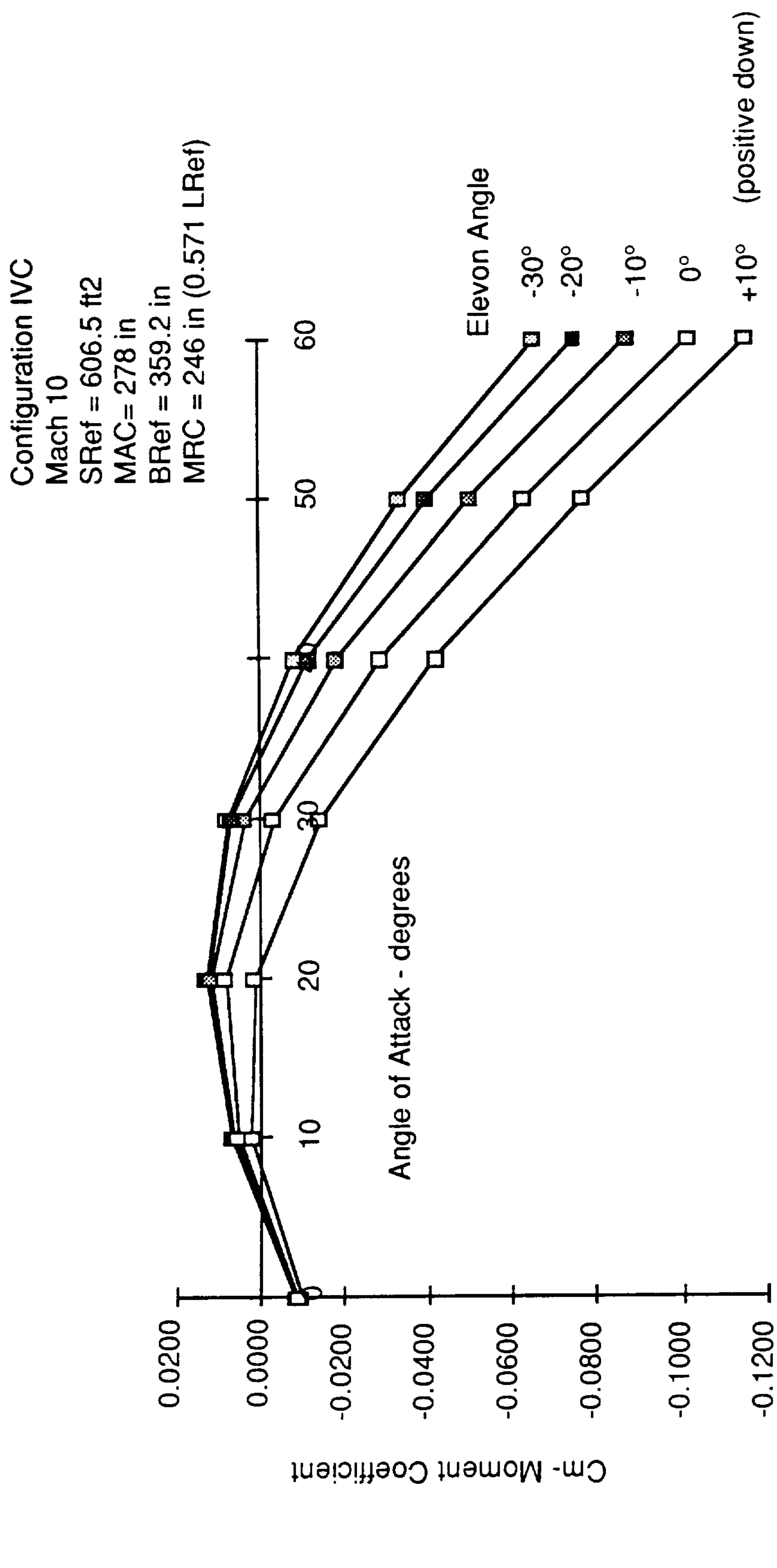


Figure 21.1-5. Configuration IVC - Hypersonic Elevon Effectiveness

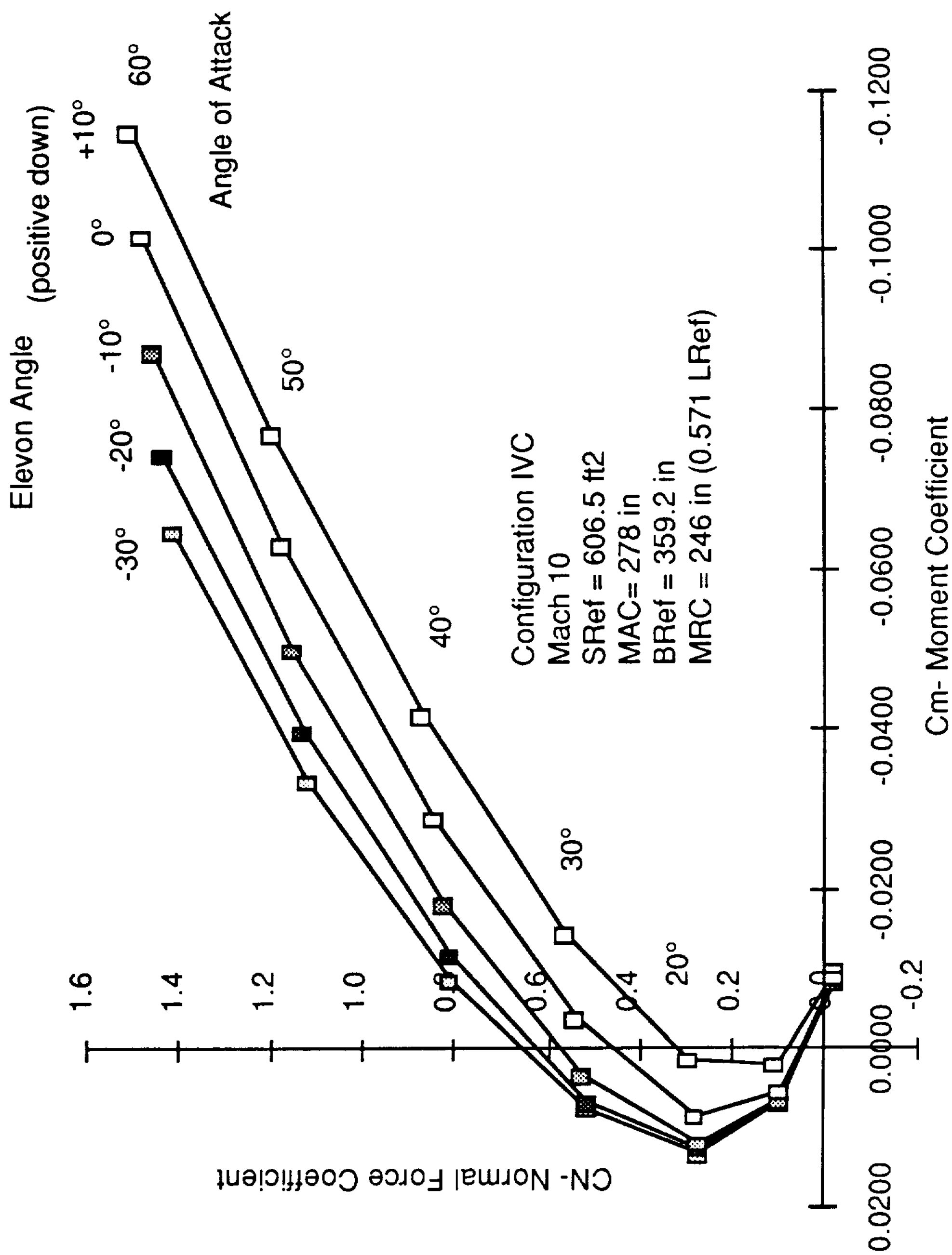


Figure 21.1-6. Configuration IVC - Hypersonic Stability Characteristics

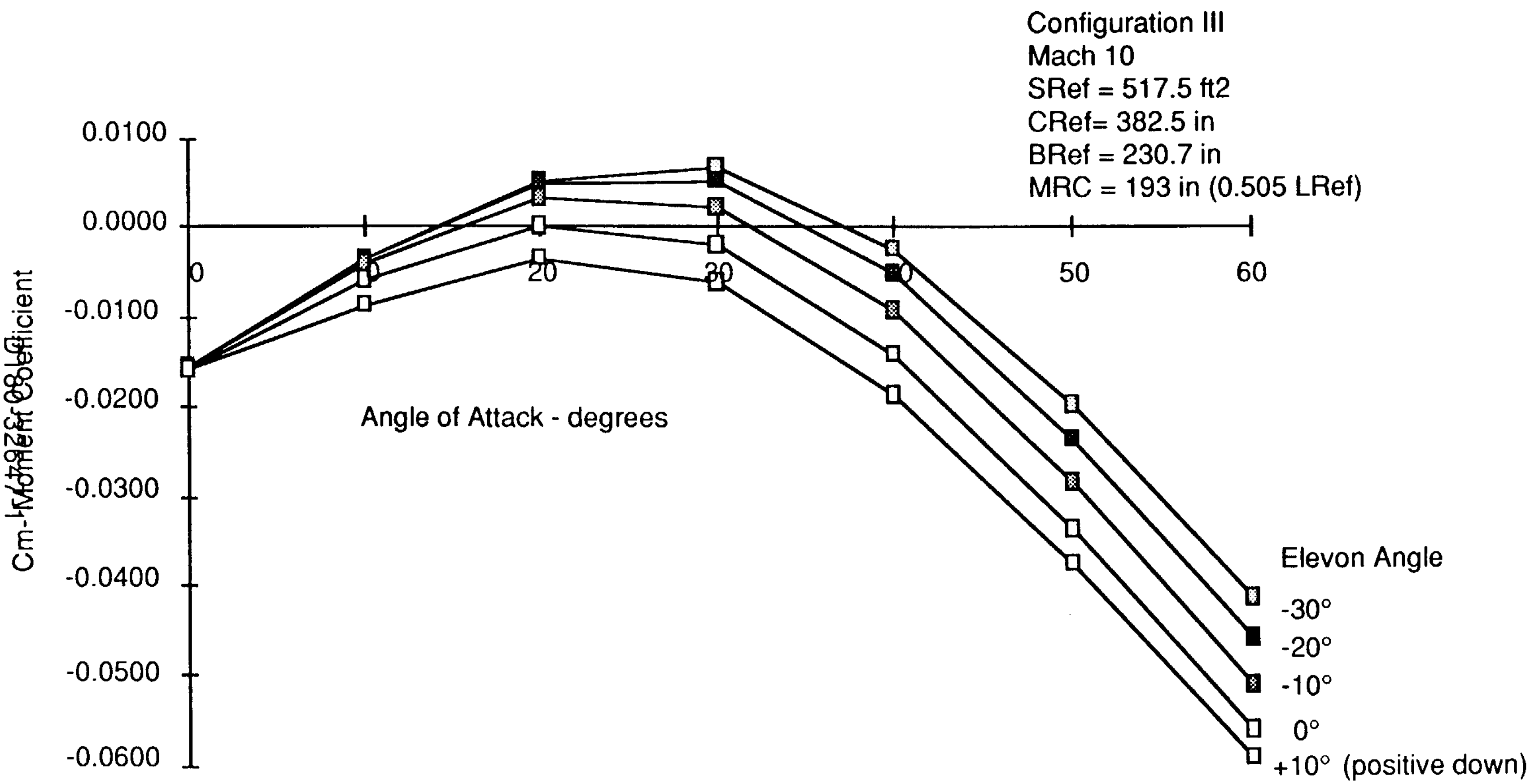


Figure 21.1-7. Configuration III - Hypersonic Elevon Effectiveness, Small Elevon

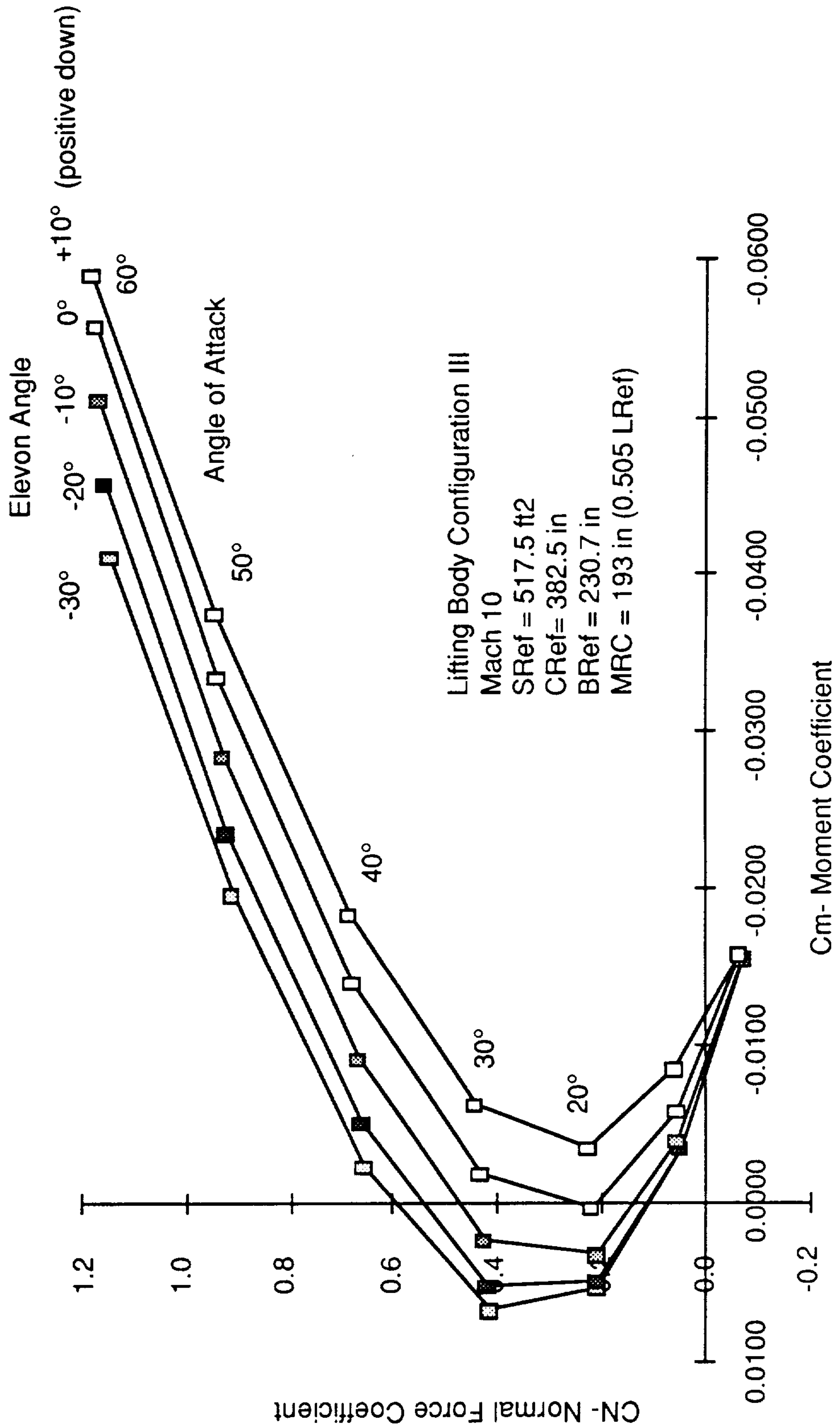


Figure 21.1-8. Configuration III - Hypersonic Stability Characteristics, Small Elevon

Lift and drag characteristic are compared in Figures 21.1-9 and 21.1-10 for these configurations. Hypersonic lift curve slope and maximum lift are higher for the wing-body than for the lifting body. The biconic data is referenced to base area and is only comparable in terms of lift-to-drag. The highest hypersonic lift-to-drag is obtained by the wing-body shape (1.6) followed by the lifting body (1.1) and biconic (0.9) respectively.

Mach 10
Configuration II, SRef = 148 ft2
Configuration III, SRef = 517.5 ft2
Configuration IVC, SRef = 606.5 ft2

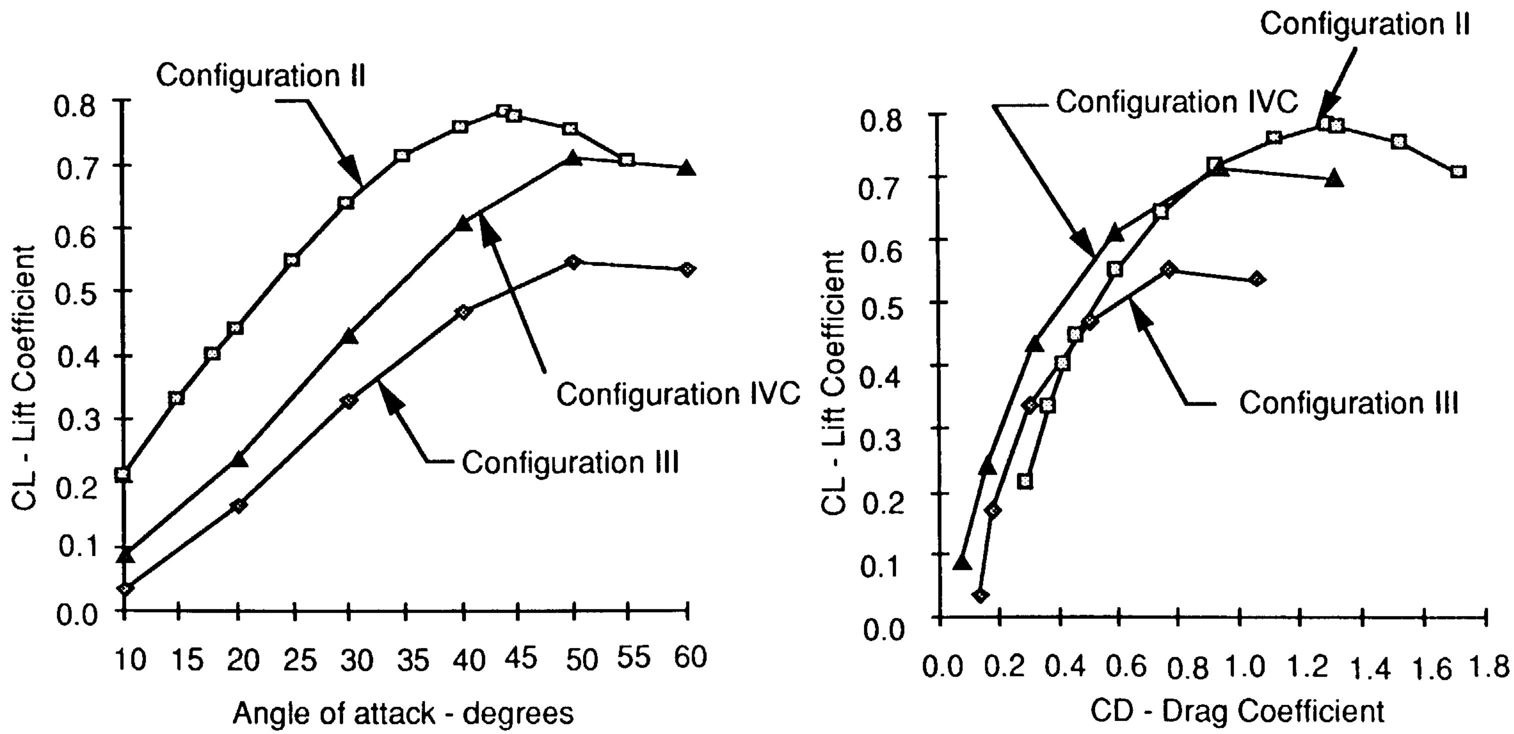


Figure 21.1-9 Vehicle Subsonic Aerodynamics

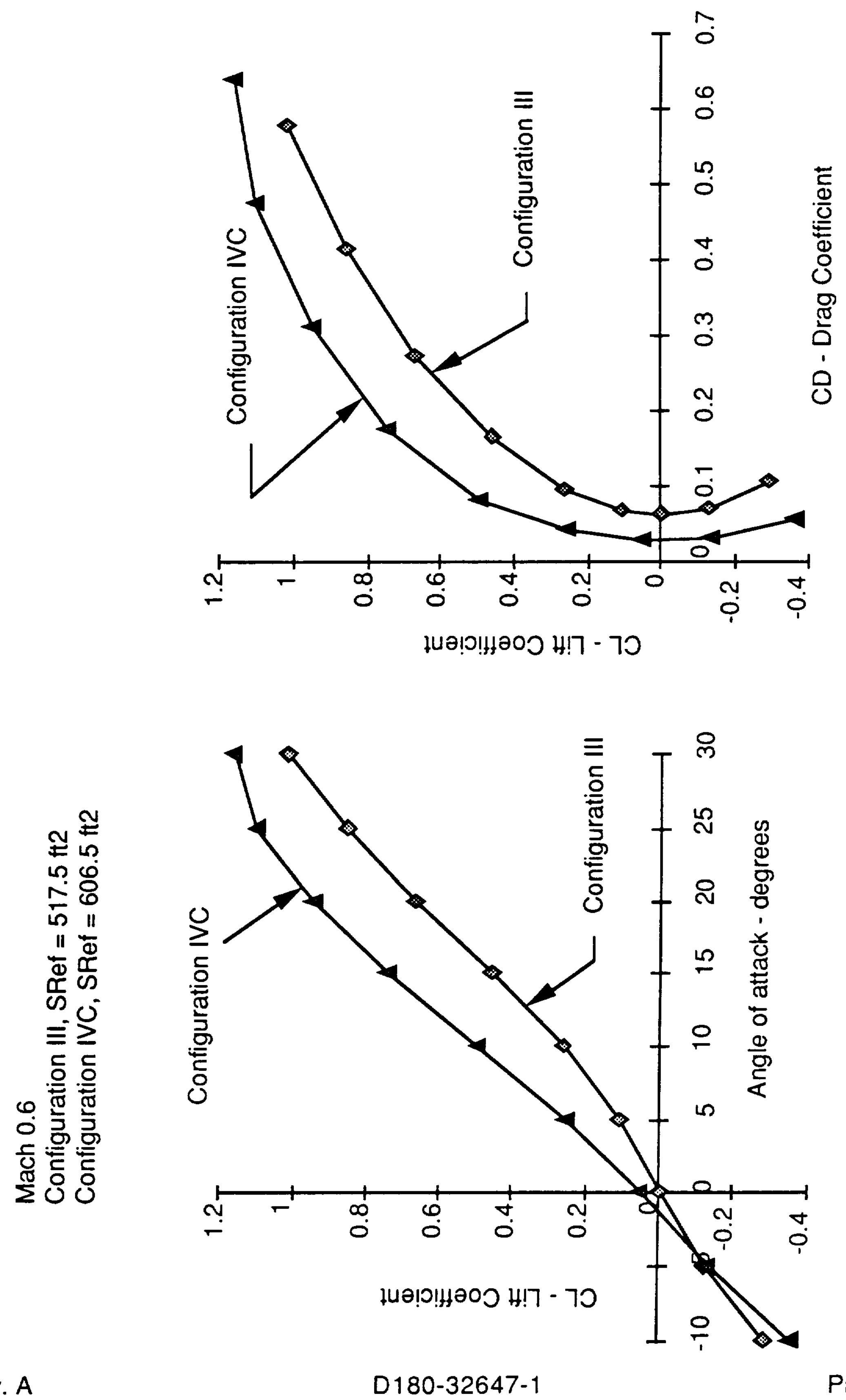


Figure 21.1-10 Vehicle Subsonic Aerodynamics

The subsonic lift curve slope is higher for the wing-body than for the lifting body. The drag is substantially higher for the lifting body. This result in a poor subsonic lift-to-drag for the lifting body, i.e., less than 3.0 during landing. The consequence is poor landing characteristics for the lifting body. The subsonic lift-to-drag of the wing-body is greater than 4 during landing and comparable to the Shuttle Orbiter.

21.2 Stability and Control

Reaction Control System (RCS) for Low L/D Configurations - Low L/D configurations will generate lift to control the re-entry path in response to guidance commands. RCS torque will be required to counter the moments from center of gravity (c.g.) offsets and to hold the angle of attack (and roll angle) required to generate the desired lift vector. The placement of thrusters and resulting torque capability are dependent on the specific configuration, but the resulting characteristics are comparable for a wide range of configurations. Figure 21.2-1 shows plots of trimmed (i.e. zero moment) angles of attack for various c.g. offsets and Mach numbers for a typical example. This configuration is axially symmetric, so the c.g. offset can be used to define the vertical flight plane. The nominal trim condition would be established for hypersonic flight at, say, L/D=.29. Note that significant RCS activity would be required to hold the same angle at subsonic speeds.

A more appropriate control policy for efficient use of the RCS would re-trim the angle of attack as the speed changed, as indicated by the dashed line. Guidance would then be provided with the altered L/D conditions. Since the major changes in L/D occur at very low speeds, guidance will have largely completed its function and the effect of reduced L/D on the trajectory would be small. Figure 21.2-2 shows RCS torque and fuel usage for a typical re-entry trajectory using either the constant angle of attack policy or the trimmed policy. Note that most of the activity occurs late in the flight and that trimming makes a very significant difference in the amount of fuel. Thus requirements for RCS fuel are determined by the detailed design of the vehicle configuration and the guidance and control algorithm capability.

The biconic configuration for low L/D vehicles has a preferred orientation relative to the vertical flight plane. Thus c.g. offsets can occur along both the y- and z-axes. To reduce the RCS fuel requirements a split body flap is included for trimming both pitch and roll. Actuation of the flap would be slow to limit the size of the required motor, and

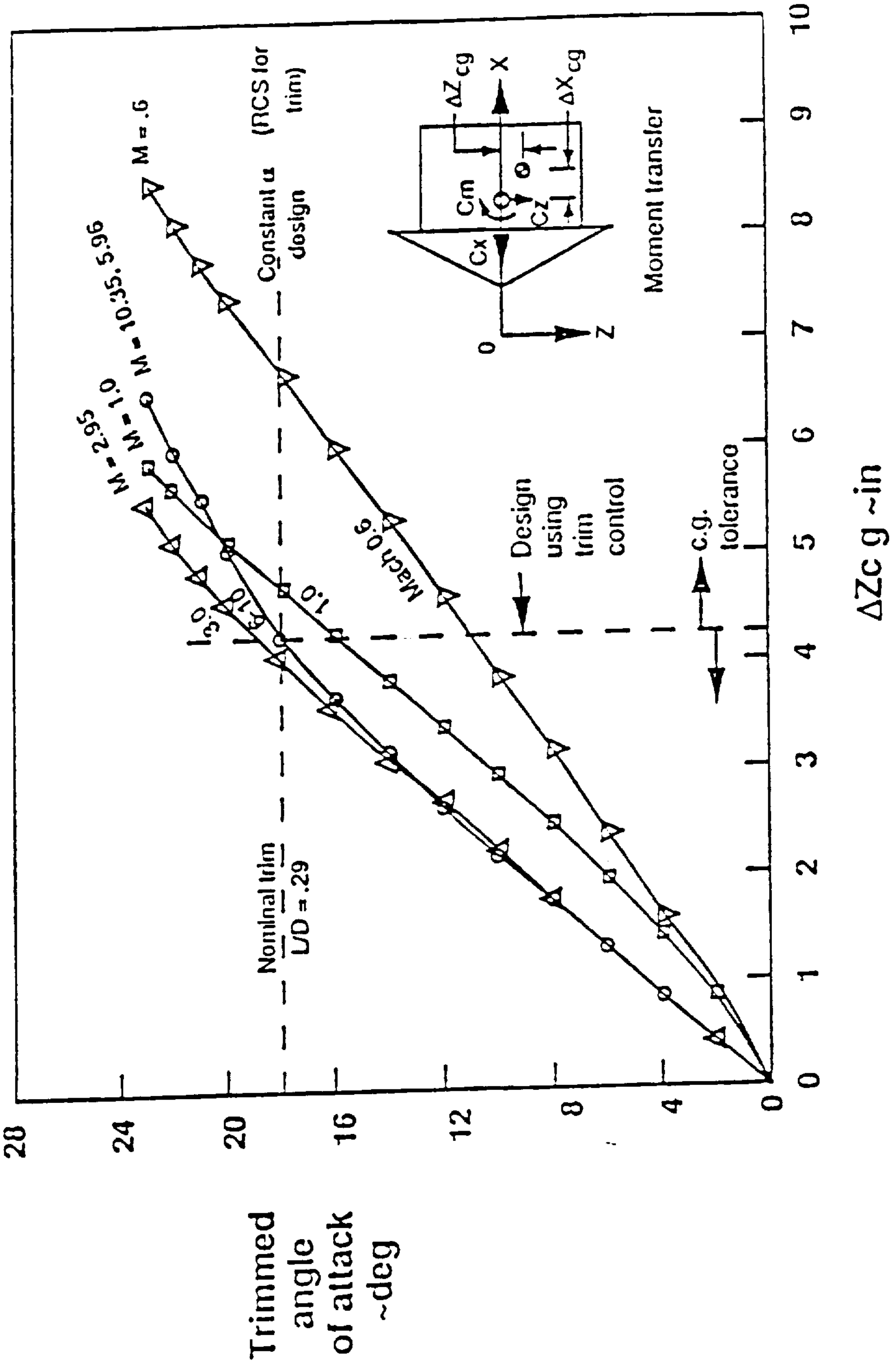


Figure 21.2-1. Example Pitch Trim Map

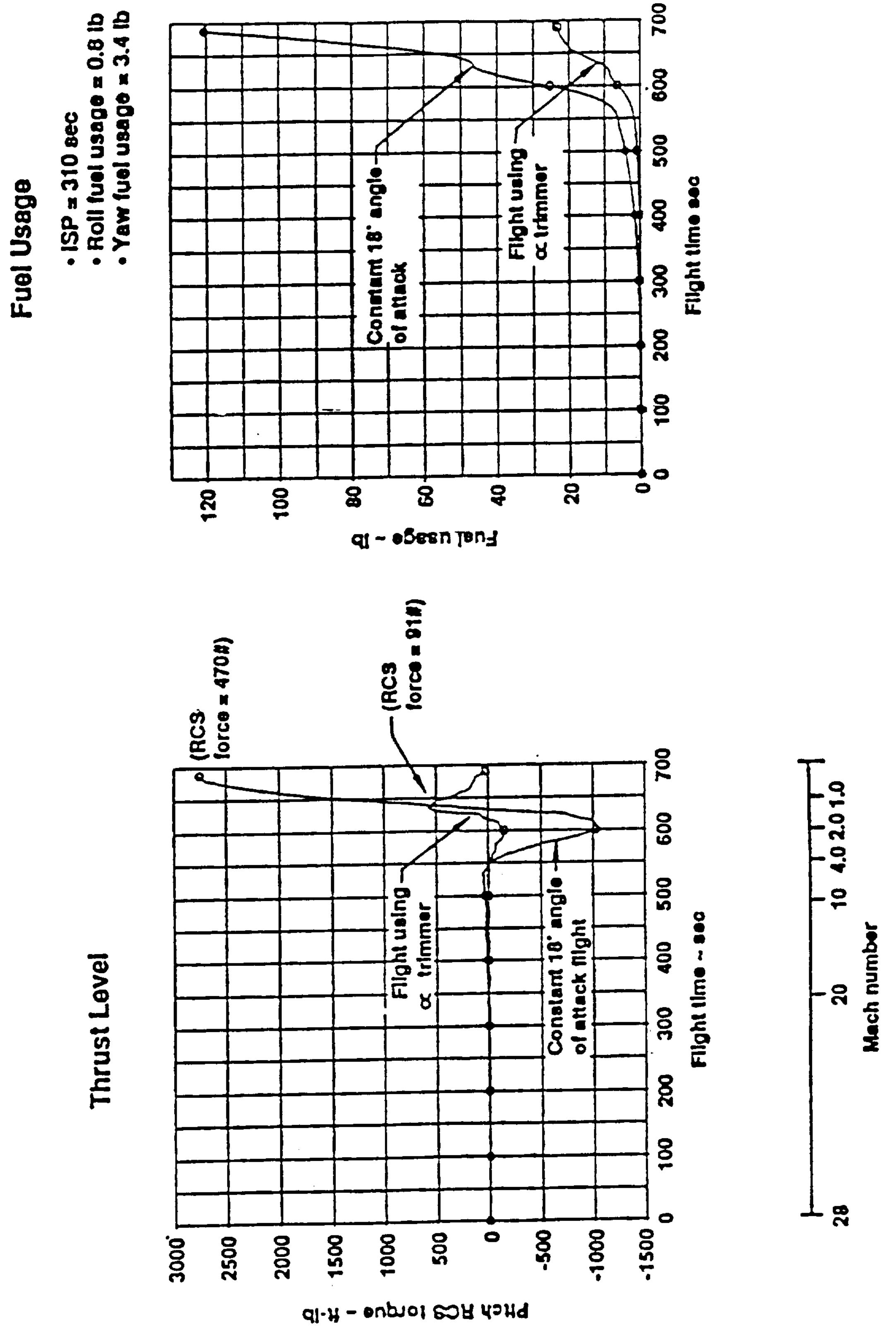


Figure 21.2-2. RCS Fuel Usage for Reentry

some RCS augmentation would be needed to accommodate aerodynamic variations. Figure 9.5-4 (in the previous report) shows a typical pitch trim map for such configurations. Splitting the flap is necessary to counter roll moments which would produce excessive yaw rotation due to roll/yaw coupling.

Approach and Landing Design Considerations for High L/D Configurations - Three areas of concern in the landing and approach phase are considered in this study. 1) As an un-powered vehicle, it should have a sufficient L/D value that results in a reasonable glide path angle. A steep glide path angle requires a severe pull up maneuver which may result in excessive loss of speed. In addition, for a given desired landing speed, the corresponding angle of attack at landing should not result in tail scraping. 2) The vehicle should have enough lateral control authority to decrab the vehicle in the presence of 22 knots side wind (constant). 3) The elevator should have sufficient effectiveness to balance the nose down moment on main gear at landing.

Figure 21.2-3 shows the landing characteristics of each of the high L/D configurations considered. As expected, the higher the L/D value of the vehicle, the lower the angle of attack at landing, as well as the glide slope angle. Conversely, given the angle of attack at landing, the landing speed required for a winged vehicle is much lower than the lifting body configuration. The pitch and yaw/roll static stabilities for the vehicle considered are stable at low speed for a c.g. location at about the center of the vehicle.

	Configuration	Lifting Body (L/D = 2.76)	Small Winged Vehicle (L/D = 4)	Medium Winged Vehicle (L/D = 6)	Langley Vehicle HL20 (L/D = 3)
Pitch	Angle-of-attack @ landing speed of 175 knots	15.8°	13°	8.7°	
Pitch	Landing Speed @ 16° angle-of-attack	175 knots	159 knots	120 knots	
Pitch	Glide Slope Angle	25°	15°	15°	
Pitch	Pitch Stability @ Landing, $C_{M\alpha}$	Stable	Stable	Stable	
Yaw Roll	Fin Deflections @ 22 knots side wind	δ_a= 33.86° δ_r = -18.5 ϕ = 3°		δ_a= 13 δ_r= 25.6° ϕ = 7°	δ_a= 27.7 δ_r= -10.3° ϕ = 11°
Yaw Roll	Maximum Side Wind Capability	19 knots		26 knots	22 knots
Yaw Roll	Yaw-Roll Stability @ landing, $N_{\beta} - \alpha L_{\beta}$	Stable	Stable	Stable	

Figure 21.2-3 Comparison of Landing Characteristics

In the presence of 22 knots side wind, which was selected as consistent with aircraft type operations (for comparison, the Shuttle Orbiter limit is 15 kts), the fin deflections and bank angle required to decrab and trim the vehicle are shown. The lifting body configuration requires the largest fin deflection. If the maximum fin deflection is limited to 30° (typical actuation limit), the maximum side wind capability each of the vehicle is also tabulated. Figure 21.2-4 summarizes the landing feasibility of the vehicles against the points of concern discussed above. For the winged vehicles, they both have acceptable L/D value for gliding and sufficient lateral control authority for decrab. As for the lifting body, the steep glide slope resulting from the low L/D characteristic requires precise timing and control of angle of attack and airspeed during the flare maneuver. An autoland system may be needed to alleviate the pilot's tasks. The lifting body has limited roll control capability due to the inefficiency of the differential split body flap.

Configuration	Lifting Body	Small Winged Vehicle	Medium Winged Vehicle	Langley Vehicle HL 20
L / D	Steep glideslope (may need autoland system)	Acceptable	Acceptable	Compatible with Space Shuttle glide slope
Decrab Capability	Potential problem (lack of roll control authority)		Acceptable	
	*			

* Function of rear wheel location, vehicle sink rate and elevator control effectiveness.

Figure 21.2-4 Landing Feasibility Summary

The ability to balance the nose down moment on main gear at landing is a function of the rear wheel location, vehicle sink rate at touchdown, and elevator control effectiveness. Because the winged vehicle has a higher L/D value, it has a better gliding capability, and therefore a better capability to reduce the sink rate and impact at touchdown.

Re-entry phase design considerations for high L/D configurations - Design considerations in the re-entry phase are the cross range capability, angle of attack trim range, sensitivity to c.g. location uncertainty, guidance technique, and static stability.

Figure 21.2-5 shows the vehicle performance against these criteria. As expected, the winged vehicle has a larger cross range capability due to the higher L/D configuration. Like the NASA Langley HL-20 vehicle, the lifting body (Configuration III) exhibits a narrow angle of attack trim range characteristic at the hypersonic regime. Figures 21.2-6 and 21.1-5 show the elevator effectiveness for the HL-20 and the medium wing vehicle (Configuration IVC) at Mach 10 respectively. The angle of attack trim range (i.e. C_M=0) for the HL-20 is approximately $\pm 1^\circ$, while for Configuration IVC it is $\pm 8^\circ$. Figure 21.2-7 shows the HL-20 trim range as a function of Mach.

Configuration	Lifting Body	Small Winged Vehicle	Medium Winged Vehicle	Langley Vehicle HL 20
Cross Range	500 nm	700nm	800nm	
Guidance Technique	Modulating bank angle		Modulating bank angle and angle of attack	Modulating bank angle
α - Trim Range	Small ($\pm$ 1°)		Acceptable ($\pm$ 8°)	
	Sensitive, (affect trim angle, therefore L/D)		Acceptable	

Figure 21.2-5 Vehicle Characteristics Summary

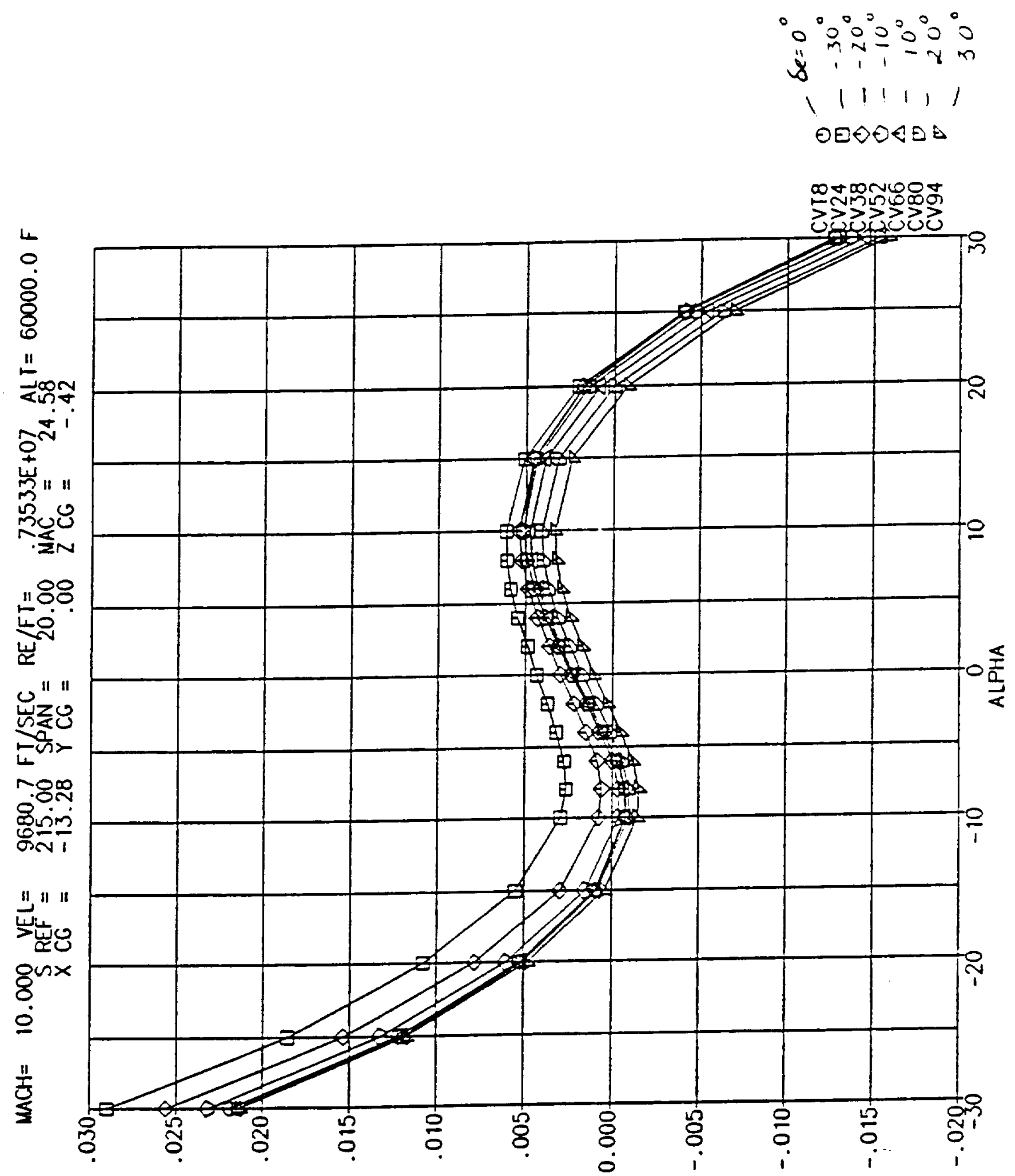


Figure 21.2-6. Elevator Effectiveness for the HL-20

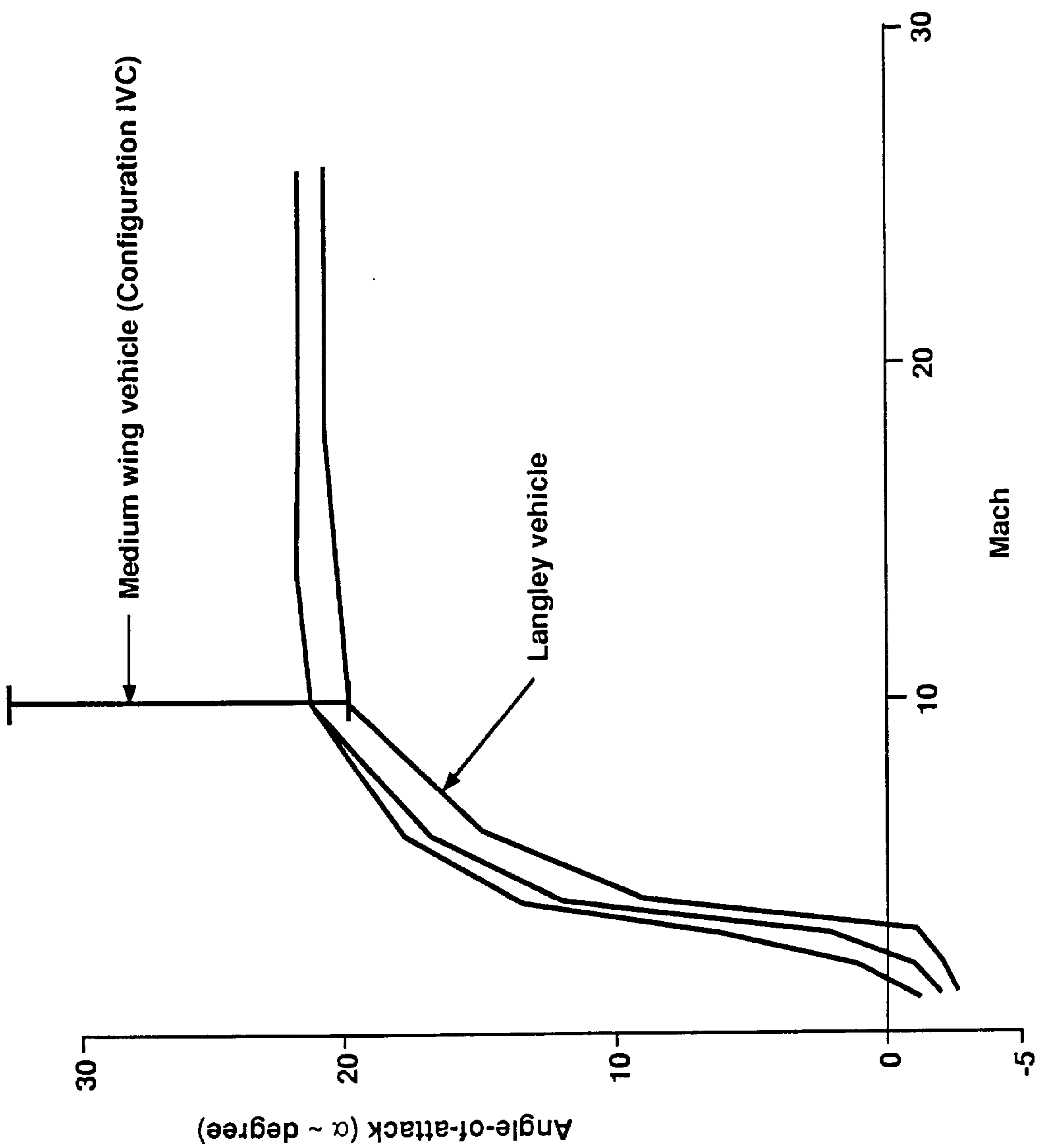


Figure 21.2-7. Trim Range as a Function of Mach

The c.g. uncertainty sensitivity and guidance technique are directly influenced by the narrow angle of attack trim range characteristic of the vehicle. Figure 21.2-8 shows the HL-20 sensitivity to the c.g. location uncertainty. For a one percent change in c.g. location, the vehicle must fly at a different angle of attack in order to stay trimmed; as a result, the re-entry profile must be adjusted to compensate for the difference in L/D value. The medium wing vehicle (Configuration IVC) is less sensitive to c.g. location uncertainty due to the effectiveness of its elevator.

Because of the narrow angle of attack trim range characteristic, the HL-20 and lifting body vehicle (Configuration III) performs banking maneuver to dissipate the excessive lift in the vertical plane. While the wing vehicles have the option of reducing lift by reducing angle of attack.

The static stability of the considered vehicles are stable for a c.g. location of 55% body length at the hypersonic regime, except in the yaw roll plane under a certain angle of attack conditions; however, these angle of attacks occur in the untrimmable range in the pitch plane, therefore the instability is not considered to be critical.

Piloting Considerations - The major piloting task (when autoland systems are inoperative or unavailable) for lifting re-entry vehicles with horizontal landing capability is the approach and landing task. A limited amount of analysis on flying qualities for such vehicles exists. It is primarily related to Space Shuttle; however, the landers considered in this study are expected to have similar pitch and flight path response characteristics. All such configurations would have highly augmented control systems, so that their response is dominated by control system parameters rather than aerodynamic modes. Essentially their transient response in pitch is not as quick as aircraft in comparable flight conditions and the coupling between attitude response and flight path angle is different. Thus pilots tend to rate them lower in flying qualities than high-performance aircraft .

Reference 27 compares the response of the Shuttle with that of several highly augmented aircraft configurations that were rated by two pilots using the Cooper-Harper scale and the Mil Spec 8785 scale. Figure 21.2-9 shows the pitch step response of the Shuttle Orbiter, compared to its design specification, and responses of the rated aircraft configurations. Studies of the NASA HL-20 show pitch step response very similar to the Shuttle Orbiter. Note that the configurations having such response

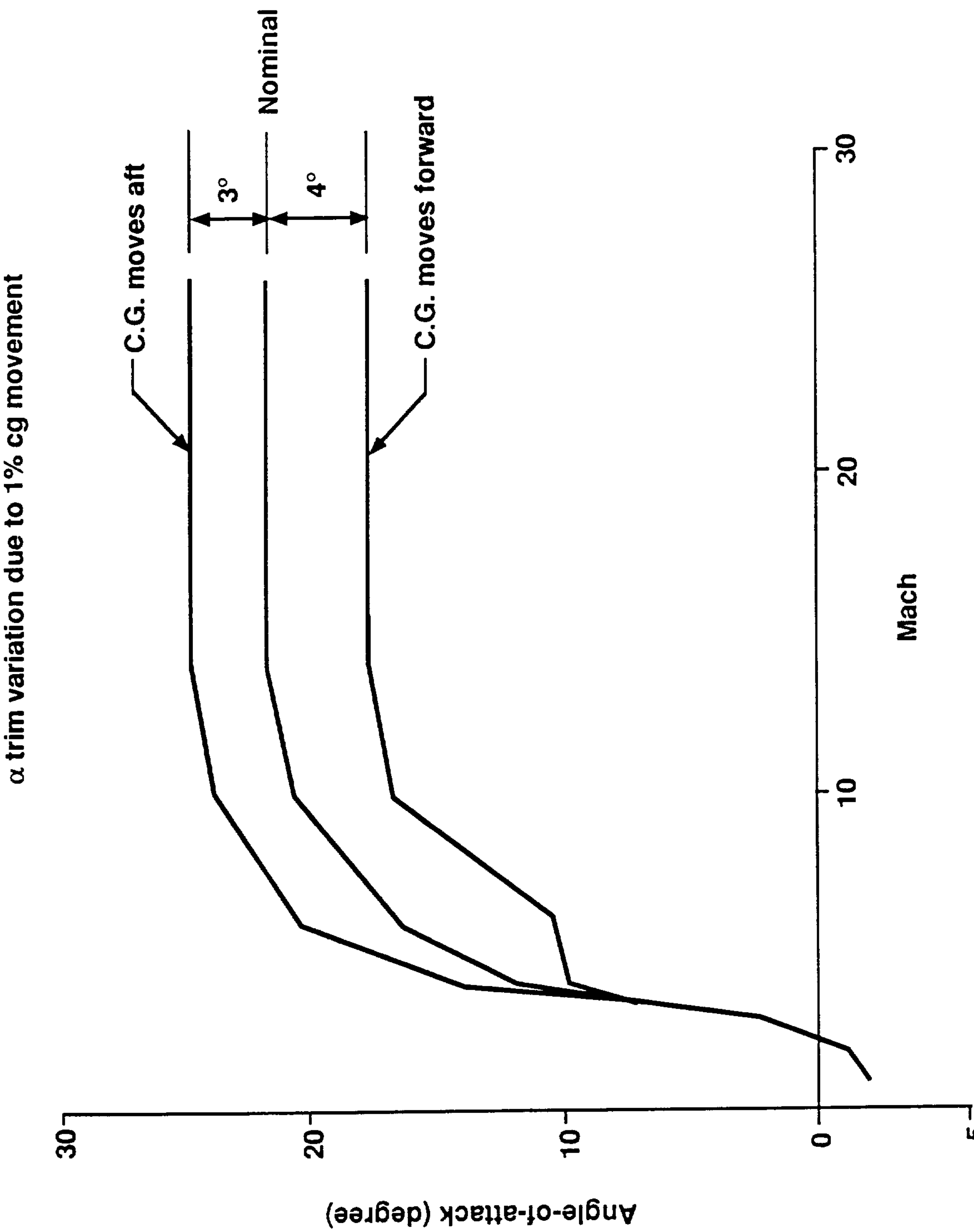
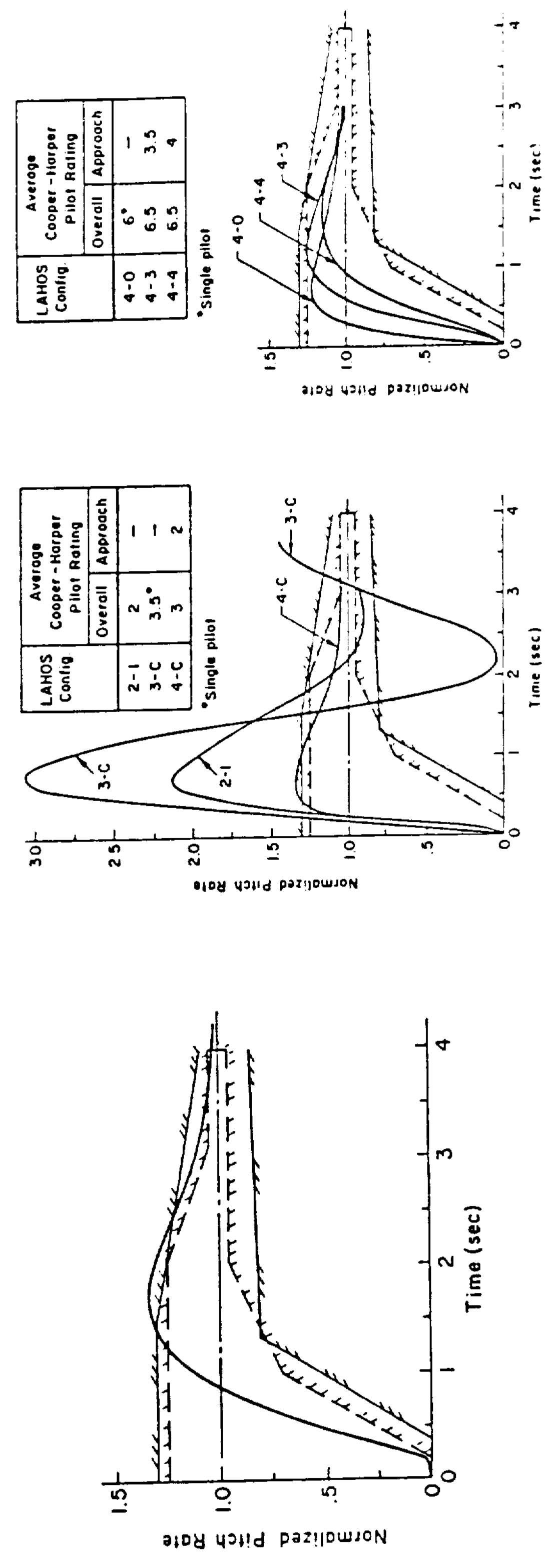


Figure 21.2-8. HL-20 Trim Range Versus Mach



LAHOS Config	Average Cooper-Harper Pilot Rating	
	Overall	Approach
2-1	2	—
3-C	3.5*	—
4-C	3	2

*Single pilot

LAHOS Config	Average Cooper-Harper Pilot Rating	
	Overall	Approach
4-0	6*	—
4-3	6.5	3.5
4-4	6.5	4

*Single pilot

Figure 21.2-9. Pitch Response Comparison

are rated near the middle of the Cooper-Harper scale, indicating that they are flyable but not comfortably so. The primary problem is the delay in rise time and slow settling, requiring pilot anticipation of pitch attitude changes.

The landing flight conditions for these lifting re-entry vehicles involve steep approach flight path angles, large flare maneuvers to reach touchdown flight path angles, tight timing of the flare with tight control of angle of attack and airspeed. In addition a decrab maneuver is necessary in cross wind landings. Given these requirements and the flying qualities characteristics described above, piloting will involve significant training and practice to develop and maintain proficiency.

21.3 Mass Properties

Mass properties analysis was performed using analysis tools and techniques similar to those described in the previous sections of the report. Subsystem assumptions were held constant wherever possible.

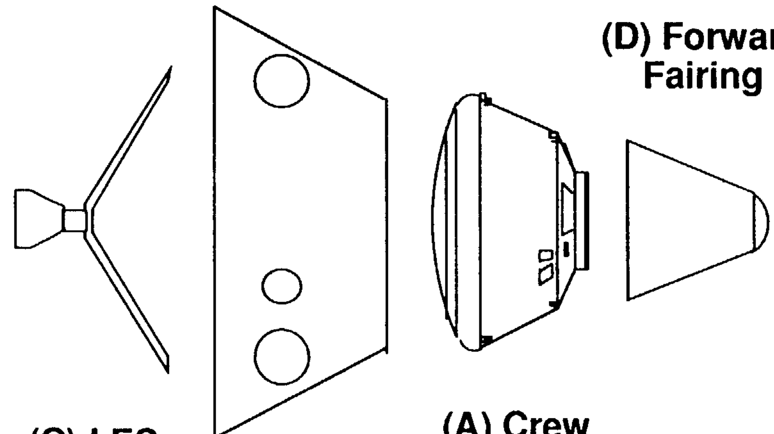
Table 21.3-1 is a summary mass statement for Configuration I. Detailed numbers can be found as Table 21.3-2. For a six person version of Configuration I, Table 21.3-3 describes the associated masses.

Table 21.3-1 Summary Weight Statement - Configuration I

Crew / Passengers: 2 / 8 — Mission Duration : 72 Hour

Functional System	A	B	C	D
1. Structure	5036	1705	329	466
2. Protection	1928	57		
3. Propulsion	426	1322	2176	
4. Power - Electrical	2157	188		
5. Control	0			
6. Avionics	1587			
7. Environment	1471	795		
8. Other - Personnel Provisions	1486			
Other - Landing, Aux Systems	1609	174		
9. Weight Growth Margin	2355	636	376	70
Dry Mass	**18056**	**4877**	**2881**	**536**
10. Non-Cargo (See Note 1)	3333	766	329	
11. Cargo	0	0		
Inert Mass	**21389**	**5643**	**3210**	**536**
12. Non- Propellant Consumables	855			
13. Propellant - Nominal	376	3029		
Gross Mass	22620	8672	3210	536
	31292		3746	
Total Mass	**35038**			

Configuration: Low L/D Crew Module



All Mass in Pounds

Notes:
A Crew Module
B OMS / Radiator Module
C Launch Escape System (LES)
D Fwd Fairing

[1] Includes Flight Crew + Equipment (600 Lb), Passengers +Equip (2400 Lb), And Propellant Reserves / Residuals

Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 1 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)
NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE	XCG	REMARKS	WG%
PERSONNEL		10			
CREW		2			
PASSENGERS		8			
MISSION DURATION (DAYS)		3.0			
ECLSS					
CLOSURE LEVEL		OPEN			
PRESSURIZED VOLUME -CABIN (FT3)		1092.0			
PRESSURIZED VOLUME -AIRLOCK (FT3)		0.0			
PRESS/REPRESS EVENTS		2.0			
CABIN LEAKAGE (%VOLUME/DAY)		2.0			
PROPULSION		Delta V Isp,sec			
RCS - H2O2/RP		146 310			
COLD GAS - N2		10 60			
OMS - LO2/RP		989 315			
LES - Expend Liquid Pusher		606 310			
ON-PAD ABORT WEIGHT		35038			
ON-ORBIT WEIGHT		31293			
LANDING WEIGHT		21101			
DESIGN LANDING WEIGHT		22000			

Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 2 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
STRUCTURE - BODY GROUP				**5036**	**160**			**15**
FWD BODY BASIC STRUCTURE			932			(X.127- X.230)	ALUM SKIN / STR	
TUNNEL	1	42			223	S= 21 SF @ 2.0 PSF		
FWD CONIC - STA. 202-217	1	142			210	S= 71 SF @ 2.0 PSF		
MAJOR FRAME - STA 202	1	92			202	L = 38 ft, A=2.0 in2		
MINOR FRAMES	1	46			165	L = 19 ft, A=2.0 in2		
JOINTS, SPLICES, FASTENERS		48			170	15% OF FRAMES, BULKHEADS		
COVER PANELS - MID BODY (LESS ACCESS)		520			165	S=306 SF @ 1.7 PSF		
LONGERONS - FWD BODY	6	84			165	L= 5.8 FT ea, A=2.0 IN2		
AFT BODY / HT SHIELD BASIC STRUCTURE			926			(X.88- X.127)	ALUM SKIN / STR	
MAJOR FRAME - STA 127	1	136			127	L= 56 FT, A=2.0 IN2		
COVER PANELS - HEAT SHIELD		790			110	S=316 SF @ 2.5 PSF		
FWD BODY SECONDARY STRUCTURE			343					
WINDOW, THERMAL	6	44			202	S,ave=0.8 SF EA @ 9.0 PSF		
WINDOW, RETAINER	6	15			202			
ACCESS PANELS	2	48			138	S= 8 SF EACH @3.0 PSF	ALUMINUM	
PARACHUTE COVER PANELS	2	48			210	S= 8 SF EACH @3.0 PSF	ALUMINUM	
RMS GRAPPLE FITTING	2	44			210			
EQUIPMENT SUPPORT GUSSETS	12	144			127	S= 6 SF EA.@ 2.0 PSF	ALUMINUM	
AFT BODY / HT SHIELD SECONDARY STRUCT			40					
SERVICE MODULE UMBILICAL PLATE	1	20			130			
LAUNCH/PROP MODULE UMBIL PLATE	1	20			130			
CREW MODULE BASIC STRUCTURE			1821				ALUMINUM SKIN / STRINGER	
BULKHEAD, FWD	1	265			185	S=106 SF @ 2.5 PSF	ALUMINUM	
BULKHEAD, AFT	1	158			102	S= 93 SF @ 1.7 PSF	ALUMINUM	
MINOR FRAMES, CABIN	5	383			170	L, ave= 42 FT , A= 1.5 IN2	ALUMINUM	
COVER PANELS, TUNNEL	TBD	95			201	S=56 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, CUPOLA BULKHEADS	4	62			200	S=5.2 SF EA @ 3.0 PSF	ALUMINUM	
COVER PANELS, UPPER CONIC	TBD	303			164	S=178 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, LOWER CONIC	TBD	338			124	S= 199 SF @ 1.7 PSF	ALUMINUM	
FLOORING, EQUIP SUPT		184			118	S= 92 SF @ 2.0 PSF	ALUMINUM	
FTGS, CABIN ATTACHMENT	22	33			164			
CREW MODULE SECONDARY STRUCTURE			974				ALUMINUM SKIN / STRINGER	
EQUIPMENT SUPPORT RACKS	2	75			85	S=50 SF @ 1.5 PSF		
EQUIPMENT BAY / CREW DECK	2	81			135	S=27 SF EA. @ 1.5 PSF		
FLT SEAT SUPPORT STUCT	2	60			135	S=20 SF EA @ 1.5 PSF		
WINDOWS	6	130			202	S= 0.8 SF EA @ 27 PSF		
WINDOWS, RETAINER	6	65			202			
DOCKING ADAPTER MECHANISM	1	340			230			
AIRLOCK INTERFACE RING	0	0			0	L= 13.0 FT, A= 2.5 IN2 + 20%	ALUMINUM	
TOP HATCH, STRUCTURE	1	72			217	40-IN DIA, SHUTTLE-TYPE (8.7 sf)		
TOP HATCH, MECHANISM	1	41			217			
SIDE HATCH, STRUCTURE	1	58			168	36-IN DIA		
SIDE HATCH, WINDOW & RETAINER	1	20			168			
SIDE HATCH, MECHANISM	1	32			168			

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Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 3 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PROTECTION				**1928**	**134**			**15**
EXTERNAL TPS - BODY			1441					
BODY TPS - HRSI (HEAT SHIELD)		929			110	S=316 SF @ 2.94 PSF	FRCI-12 w/SiC cover	
BODY TPS - LRSI (MID)		431			164	S=306 SF @ 1.41 PSF	FRCI-12	
BODY TPS - FRSI		58			210	S=112 SF @ .522 PSF	Rigid TABI	
ACCESS PANEL TPS - LRSI		23			140	S= 16 SF @ 1.41 PSF	FRCI-12	
INTERNAL INSULATION / TCS			406					
BULK INSULATION - EQUIPMENT BAYS		110			127	S= 314 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSULATION - EQUIP BAYS		22			127	S= 314 SF @ 0.07 PSF	MLI	
BULK INSULATION - CREW MODULE		228			155	S= 650 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSUL. - CREW MODULE		46			155	S= 650 SF @ 0.07 PSF	MLI	
PURGE AND VENT SYSTEM			63			SCALED FROM SHUTTLE		
DUCTING		30			127			
VALVES		20			127			
SUPPORT, INSTALLATION		13			127			
WINDOW / HATCH CONDITIONING			19			SCALED FROM SHUTTLE		
PLUMBING		7			202			
DESSICANT, VALVES, DISCONNECTS		8			202			
SUPPORT, INSTALLATION		4			202			
RECOVERY & AUXILIARY SYSTEMS				**1609**	**188**			**15**
PARACHUTE SYSTEM			1518		190			
DROGUE CHUTES	1	290						
BACKUP DROGUE	1	290						
MAIN CHUTE - BALLISTIC	1	400						
BACKUP CHUTE	1	400						
PARACHUTE SUPT/INSTL		138					10 % OF SYSTEM	
LANDING AND RECOVERY			12		210			
WATER FLOTATION COLLAR ASSY	4	12						
SEPARATION			79					
PARACHUTE COVER SEPARATION SEPA	2	12			210	L= 24 FT @ 0.5 LB/FT	SUPER-ZIP	
FWD CONIC SEPARATION	1	22			202	L= 43 FT @ 0.5 LB/FT	SUPER-ZIP	
RADIATOR / ADAPTER SEP BOLTS	3	45			110			

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Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 4 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PROPULSION - REACTION CONTROL				**426**	**145**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
THRUSTER MODULES - FORWARD			97		192			
THRUSTERS - RCS	8	66						
THRUSTERS - COLD GAS	6	22				MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTER MODULE SUPPORT	4	9				10 % OF SYS		
THRUSTER MODULES - AFT			55		138			
THRUSTERS - RCS	6	50						
THRUSTERS - COLD GAS	0	0				ON RADIATOR MODULE		
THRUSTER MODULE SUPPORT	4	5				10 % OF SYS		
PRESSURIZATION SYSTEM			49		127			
GN2 BOTTLE(S) - RCS	2	14						
REGULATORS	2	9				FAIRCHILD		
FILL & DRAIN DISCONNECTS	1	1				PYRONETICS		
MANIFOLD/PLUMBING		10				BOEING		
TANK VENT / RELIEF		9						
PRESS SYS SUPPORT		6				15 % OF SYS		
PROPELLANT SUPPLY - RCS			202		127			
TANKAGE - H2O2	2	60				31.0-IN DIAMETER SPHERICAL	NEW	
TANKAGE - RP	2	22				16.5-IN DIAMETER SPHERICAL	NEW	
DISCONNECTS	2	2						
VALVES	9	35				CONSOLIDATED CONTROLS		
MANIFOLD/PLUMBING	1	40				BOEING 304L SS		
TANK FILL, VENT & DRAIN	2	25						
PROPELLANT SUPPLY SUPPORT		18				10 % OF SYS		
PROPELLANT SUPPLY - PROX-OPS (fixed)			23		165			
FLIGHT DISCONNECT	1	1				PYRONETICS		
MANIFOLD/PLUMBING		20				BOEING 304L SS		
COLD GAS SUPPLY SUPPORT		2				10 % OF SYS		

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Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 5 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
POWER - ELECTRICAL				**2157**	**120**		**15**
POWER SUPPLY			1300			FUEL CELL SYSTEM - 6 KW NOM, 9 KW PEAK TOTAL	
FUEL CELLS	2	361			127	Reduced Shuttle Cells - 2 of 3 to supply sustained power	
BATTERIES	6	432			127	Contingency only - 48 kw-hr LI-SOCL2	
O2 TANKAGE (EPS & ECLSS)	2	90			127	20.0 in ID VACUUM -JACKETED TANK	
H2 TANKAGE	2	94			127	24.0 in ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	4	12			127		
REACTANT RELIEF, VENT PLUMBING	4	64			127		
REACTANT SUPPLY PLUMBING	4	20			127		
REACTANT SUPPLY VALVES, DISC	4	12			127		
COOLANT PLUMBING		45			127	INCL. 30 LB FLUIDS	
WASTE WATER TANK		0				INCL IN WATER MANAGEMENT	
POWER SUPPLY SUPT/INSTL		170			127	15 % OF SYS	
POWER DIST EQUIP			169				
POWER DISTRIBUTION PANELS	3	99			110		
10VDC POWER SUPPLY	3	1			110		
EXTERIOR LIGHTS		15			110	ESTIMATE	
INTERIOR LIGHTS		20			110	ESTIMATE	
POWER DISTRIBUTION SUPT/INSTL		34			110	25 % OF SYS	
WIRING			688			ESTIMATE	
POWER DISTR. WIRE HARNESSES		400			110		
INSTRUMENTATION WIRING		100			110		
ELECTRICAL CONNECTORS		50			110	BULKHEAD FEEDTHRU PLATES	
HARNESS SUPT/INSTL		138			110	25 % OF SYS	

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Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 6 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
AVIONICS				**1587**	**130**		**15**
GUIDANCE, NAVIGATION AND CONTROL			184		110		
FAULT-TOLERANT NAVIGATOR	1	50					
GPS RECEIVER	2	12					
GPS ANTENNAS	2	10					
HORIZON SCANNER	2	12					
RADAR ALTIMETER	2	10					
RCS/ OMS VALVE DRIVER	2	90					
RENDEVOUS AND DOCK			133		210		
RENDEVOUS RADAR	1	30					
RADAR SIGNAL PROCESSOR	1	70					
ANTENNA	1	8					
ANTENNA MAST, DEPLOYMENT MECHS	1	25					
VEHICLE HEALTH MONITORING			75		110	SENSORS INCL IN INSTRUMENTATION COUNT	
MASS MEMORY	3	75					
COMMUNICATIONS AND TRACKING			238		110		
CENTRAL DATA FORMATTER	1	27					
TRANSPONDER	1	16					
POWER AMP	1	18					
DIPLEXER, RF SWITCH	1	3					
AUDIO	1	40					
UHF TRANSCEIVER	1	20					
ANTENNAS	3	24					
SEARCH AND RESCUE RADIO	1	40				ESTIMATED	
SIGNAL CABLING		50				ESTIMATED	
CONTROLS AND DISPLAYS			185		175		
RECONFIG DISPLAYS / CONTROL UNITS	5	50					
ELECTRONIC INTERFACES	3	75					
RECONFIG. PUSH-BUTTON PANEL	3	30					
RMS WORKSTATION	0	0				ESTIMATE FOR SERVICING MISSION	
HAND CONTROLLERS	2	30					
INSTRUMENTATION			83		110		
SENSOR INTERFACE UNIT (SIU)	60	30					
NETWORK INTERFACE UNIT (NIU)	2	3					
SENSORS, INSTRUMENTATION	700	50					
DATA HANDLING			463		110		
FAULT TOLERANT PROCESSOR	3	99					
MASS MEMORY	3	75					
DATA BUS COUPLERS	60	30				ESTIMATED	
MDM	7	259					
STRUCTURES/MECHS CONTROLS			82				
CHUTE CONTROLLER	1	61			190		
LASER FIRING UNIT	2	20			190		
LASER INITIATORS	5	1			190		
AVIONICS SUPT/INSTL			144		110	10 % OF AVIONICS	

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Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 7 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS) **NOTE: ALL MASS IN POUNDS**

ITEM	QTY	CREW ROTATION VALUE			XCG	REMARKS	WG%
ENVIRONMENTAL CONTROL				**1471**	**120**		**15**
CABIN AND PERSONNEL SYSTEM			475				
O2 TANKAGE - CRYO STORAGE	0	0			127	INCL IN FUEL CELL REACTANT STORAGE	
O2 TANKAGE - (GAS FOR REPRESS)	1	25			127	Kevlar / Inconel	
N2 TANKAGE - (GAS FOR REPRESS)	2	96			127	Kevlar / Titanium	
PRESS PLUMBING		12			127		
CABIN PRESS & COMPOSITION CNTRLS		65			110	VALVES, VENT RELIEF VALVES, ETC	
CO2 REMOVAL - 2-BED LiOH		11			110	LiOH CANISTER UNIT - 2 CANISTER UNIT	
LiOH CANISTER STORAGE - NOMINAL		43			140	(7.0 LB/2-PERSON-DAY)	
LiOH CANISTER STORAGE - CONTING.		70			140	48-HR @(7.0 LB/2-PERSON-DAY)	
TEMP AND HUMIDITY CONTROL		127			110	FANS/SEPARATORS, HEAT EXCHANGER, ETC	
TRACE CONTAMINANT CONTROL		7			110	CANISTER FOR IMPURITY REMOVAL	
DUCTING, MISC		20			110	FANS INCLUDED IN TEMPERATURE CONTROL	
EQUIPMENT COOLING			209		110		
EQUIPMENT COLD PLATES		120				S= 60 SF @ 2.0 PSF	
AVIONICS COOLING ASSY		28				INCL HX, FANS, DUCTING	
IMU HEAT EXCHANGER ASSY	1	31					
PLUMBING		20					
DUCTING, MISC		10				FANS INCLUDED IN TEMPERATURE CONTROL	
HEAT TRANSFER WATER LOOP			161		110		
HEAT EXCHANGER - POTABLE WATER	1	17				BASED ON SHUTTLE	
PRIMARY, SECONDARY WATER PUMPS		78					
PLUMBING		30					
COOLANT IN LOOP - WATER		36					
HEAT TRANSFER FREON LOOP			270		127		
HEAT EXCHANGER - WATER-FREON	1	50				BASED ON SHUTTLE	
HEAT EXCHANGER - GSE	1	50				BASED ON SHUTTLE	
HEAT EXCHANGER - FUEL CELL	1	50				BASED ON SHUTTLE	
FREON PUMP PACKAGE	2	90					
COOLANT IN LOOP - FREON		30					
HEAT REJECTION			222		127		
AMMONIA BOILER ASSEMBLY		45				INCL AMMONIA TANK, HEAT EXCHNGR, VENT, VALVES	
COOLANT TANKAGE - WATER		14					
FLASH EVAPORATOR - WATER		58				FROM SHUTTLE	
TOPPING DUCT ASSEMBLY		78					
HIGH LOAD DUCT ASSEMBLY		27					
RADIATOR PANELS			0			INCL ON AFT ADAPTER	
ECLSS SUPT/INSTL			134		118	10 % OF ECLSS	

Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 8 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
PERSONNELPROVISIONS				**1486**	**142**		**15**
FOOD MANAGEMENT			117		140		
GALLEY		0				GALLEY UNIT, WITH WATER DISPENSER	
FOOD STORAGE UNITS		117					
WATER MANAGEMENT			63		127		
WATER STORAGE TANK	2	28				FOR POTABLE WATER STORAGE	
HANDWASH - WET WIPES		2					
WATER DISPENSER		23				WATER DISPENSER ONLY	
PLUMBING, VALVES, ETC		10					
WASTE MANAGEMENT			58		140		
WASTE WATER TANK	2	28					
COMMODE SYSTEM		15				installation scar only for crew rotation	
EMERGENCY WASTE COLLECTION		15				SHUTTLE TYPE	
FIRE DETECTION / SUPPRESSION			13		110		
SMOKE DETECTORS		7					
FIRE SUPPRESSION TANK		6				INCLUDES SUPPRESSANT	
FURNISHINGS AND EQUIPMENT			1100				
SEATS, PERSONNEL RESTRAINTS	2	200			170	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	3	300			133	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	3	300			133	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			160	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SLEEP STATIONS		0			0	NOT REQUIRED FOR TRANSFER	
INCIDENTAL EQUIPMENT	10	100			140	STORAGE FOR ASTRONAUT PERSONAL EFFECTS	
SUPPORT/INSTALLATION			135		130	10 % OF ECLSS	
CREW MOD DRY, EXCL GROWTH				**15701**	**145**		**15**
WEIGHT GROWTH MARGIN				**2355**	**145**	**15 % OF DRY WT**	
CREW MODULE DRY WEIGHT				**18056**	**145**		

Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 9 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION					REMARKS	WG%
	QTY	VALUE			XCG		
NON- CARGO ITEMS				**3333**	**148**		
CREW, WITH EQUIPMENT			3000				
FLIGHT CREW / personal effects	2	600			175	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	3	900			138	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	3	900			138	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			165	90TH PERCENTILE + 107 lb ea.	
TOOLS, MISCELLANEOUS	0	0			0		
EVA SUITS, WITH EXPENDABLES	0	0			0		
PROPELLANT RESIDUALS			64				
RCS RESIDUAL BI-PROP		46			127	RESIDUAL IN TANKS AND LINES	
RCS N2 PRESSURANT		18			127		
PROPELLANT RESERVES			269				
RCS RESERVES - BIPROP		269			127	20% OF NOMINAL PROPELLANT	
CREW MODULE INERT WEIGHT				**21389**	**146**		
NON- PROPELLANT				**855**	**132**		
IN-FLIGHT LOSSES			334				
FUEL CELL NOMINAL O2		238			127	0.71 LB/ KW -HR	
FUEL CELL NOMINAL H2		30			127	0.09 LB/ KW-HR	
FUEL CELL O2 RESERVES		48			127	20% NOMINAL	
FUEL CELL H2 RESERVES		6			127	20% NOMINAL	
FUEL CELL RESIDUAL REACTANT		13			127	ESTIMATE	
LIFE SUPPORT CONSUMABLES			521				
O2 - CRYO STORAGE		34			127	METABOLIC CONSUMPT. (2 LB/M-DAY) +20%	
O2 - GAS FOR REPRESSURIZATION		15			127	1 repress contingency + leak (0.38 LB/DAY)	
O2 - CABIN PRESSURIZATION		14			127		
N2 - GAS FOR REPRESS, LOSSES		67			127	1 repress contingency + leak (1.26 LB/DAY)	
N2 - CABIN PRESSURIZATION		63			127		
FOOD - nominal		56			140	4 LB/M-DAY	
FOOD - contingency		80			140	4 LB/M-DAY -- 48 hr contingency	
POTABLE WATER - nominal		0			140	4 LB/M-DAY supplied by fuel cells	
POTABLE WATER - contingency		92			140	4 LB/M-DAY --48 HR CONTINGENCY + resid	
EQUIP COOLING FLUIDS - AMMONIA		45			140	COOLANT FOR LAUNCH & REENTRY COOLING ONLY + 20 %	
EQUIP COOLING FLUIDS - WATER		55			140	COOLANT FOR ON-ORBIT HI-LOAD + 20 %	
PROPELLANT - NOMINAL				**376**	**127**		
RCS NOM PROPELLANT - BIPROP			376		127		
GROSS WEIGHT				**22620**	**145**		

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Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 10 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
ADAPTER / RADIATOR MODULE				**8673**	**35**			
STRUCTURE			1338		-69			
LAUNCH VEHICLE INTERFACE RING	1	316				L=86 FT, A=3.0 IN2	ALUMINUM	
CREW MODULE INTERFACE RING	1	170				L=56.6 FT, A=2.5 IN2	ALUMINUM	
MINOR FRAMES	2	256				L,AVE =71.3 FT, A=1.5 IN2	ALUMINUM	
LONGERONS	6	248				L=11.5 FT, A=3.0 IN2	ALUMINUM	
INTERMEDIATE STRUTS / FTGS	18	248				L ave=7.1 FT, A=1.0 IN2 +1.0 LB FTGS	ALUMINUM	
RADIATOR PANEL LINKAGE & HINGES	2	40						
LAUNCH / CREW MOD UMBIL PLATES	2	60						
THRUST STRUCTURE - OMS			367					
THRUST STRUTS	3	82			70	L=7.5 FT, A=2.5 IN2 +20%	ALUMINUM	
THRUST BEAMS	3	66			44	L=6.0 FT, A=2.5 IN2 +20%	ALUMINUM	
THRUST STR STABILIZING STRUTS	TBD	74			40			
ENG INTERFACE FTGS	3	9			0	ESTIMATE		
TANK SUPPORT STRUTS	8	56			35	L= 60 IN, A=1.0 IN2 + 1 LB FTGS EA	ALUMINUM	
TANK SWAY STRUTS	16	72			35	L=40 IN, A=1.0 IN2 + 1 LB FTG EA	ALUMINUM	
PRESS TANK SUPT FLANGES	8	8			40	ESTIMATE	ALUMINUM	
THERMAL PROTECTION			57		64	S= 834 SF, @ 0.0685 PSF	FOSR	
RCS THRUSTER MODULES			43		80			
THRUSTERS - RCS	2	17						
THRUSTERS - COLD GAS	6	22				MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTER MODULE SUPPORT	4	4				10 % OF SYS		
PROPELLANT SUPPLY - RCS			46		104			
DISCONNECTS	2	2						
MANIFOLD/PLUMBING	1	40				BOEING 304L SS		
PROPELLANT SUPPLY SUPPORT		4				10 % OF SYS		
PROPELLANT SUPPLY - PROX-OPS			542		60			
N2 BOTTLE(S) - OMS, COLD GAS	4	350				15-IN ID X 74-IN LONG	KEVLAR O/W Ti	
VALVES	16	82				CONSOLIDATED CONTROLS		
FLIGHT DISCONNECT	1	1				PYRONETICS		
FILL / DRAIN DISCONNECT	4	4				PYRONETICS		
MANIFOLD/PLUMBING		42				BOEING 304L SS		
TANK VENT / RELIEF		14						
COLD GAS SUPPLY SUPPORT		49				10 % OF SYS		
OMS THRUSTER MODULES			165					
ENGINES	3	150			35			
ENGINE MOUNT	3	15			42			
OMS PRESSURIZATION SYSTEM			62					
GN2 BOTTLES - OMS	0	0			0	INCL IN COLD GAS SYSTEM		
GAS VALVES	4	18			60	MOOG		
REGULATORS	2	9			60	FAIRCHILD		
FILL & DRAIN DISCONNECTS	2	2			60	PYRONETICS		
MANIFOLD/PLUMBING		10			60	BOEING 304L SS		
BOTTLE VENT / RELIEF		17			60	FAIRCHILD		
PRESS SYSTEM SUPPORT		6			60	15 % OF OMS		

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Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 11 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE		XCG	REMARKS		WG%
PROPELLANT SUPPLY - OMS			336				
LO2 SYSTEM - TANK	2	102		50	44.0 in ID TANK, WITH INSULATION	ALUMINUM	
LO2 SYSTEM - VALVES	4	16		50			
LO2 SYSTEM - MANIFOLD	1	20		50	8 FT @ 2.5 LB/FT	ALUMINUM	
LO2 SYSTEM - FILL, DRAIN, VENT	1	24		50			
LO2 SYSTEM - SUPPORT, INSTL		24		50		15 % OF OMS	
RP SYSTEM - TANK	2	70		50	35.0 in ID TANK, WITH INSULATION	ALUMINUM	
RP SYSTEM - VALVES	4	16		50			
RP SYSTEM - MANIFOLD	1	20		50	8 FT @ 2.5 LB/FT	ALUMINUM	
RP SYSTEM - FILL, DRAIN, VENT	1	24		50			
RP SYSTEM - SUPPORT, INSTL		20		50		15 % OF OMS	
PROPELLANT SUPPLY (LES - OMS)			128				
LO2 SYSTEM - DISCONNECT	1	12		18	DIA=5.0 IN		
LO2 SYSTEM - VALVE	2	40		22	DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	17		22	DIA = 5.0 IN, L=3 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12		18	DIA=5.0 IN		
RP SYSTEM - VALVE	2	40		22	DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	7		22	DIA = 5.0 IN, L=2 FT @ 3.5 LB/FT	ALUMINUM	
POWER DISTRIBUTION			188	64			
WIRING, INCL GROUND UMBILICALS		150					
EQUIPMENT SUPPORT/INSTL		38				25 % OF WIRING ALUMINUM	
ECLSS RADIATOR PANELS			795	64			
COOLANT IN PANELS - FREON		30					
FIXED PANELS	2	304			A=134 sf ea @ 1.14 psf	ALUMINUM	
DEPLOYED PANELS	2	461			A=134 sf ea (134 sf ea side) @ 1.72 psf	ALUMINUM	
OTHER - AUXILIARY SYSTEMS			174				
LAUNCH VEHICLE SEPARATION	6	90		0	EXPLOSIVE BOLT SEPARATION		
LAUNCH ESCAPE SEPARATION BOLTS	3	24		40			
CREW MODULE SEPARATION	6	60		110	EXPLOSIVE BOLT SEPARATION		
WEIGHT GROWTH MARGIN			636	64		15 % OF HARDWARE	
PROPELLANT RESIDUALS			264				
OMS RESIDUALS - IN TANKS		73		50	0.3 FT3 PER TANK		
OMS RESIDUALS - IN LINES, ENGINES		66		40	4 FT EA, 5.0 IN DIA.		
OMS PRESSURANTS		79		60	0.0251 LB/LB PROPELLANT	NITROGEN	
COLD GAS RESIDUALS		46		60			
PROPELLANT RESERVES			502				
OMS RESERVES		288		50	10% OF NOMINAL		
RCS RESERVES - COLD GAS		215		60	20% OF NOMINAL PROPELLANT		
RCS NOM PROPELLANT - COLD GAS			153	60			
OMS NOMINAL PROPELLANT			2876	50	DELTA V AS SHOWN		

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Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 12 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
LAUNCH ESCAPE SYS - JETTISONABLE				3210	104			
THRUST STRUCT. - LAUNCH ESCAPE (JETT)			329					
ENGINE THRUST STRUTS	3	52			28	L=4 FT, A=3.0 IN2 + 20%	ALUMINUM	
FEEDLINE STABILIZING STRUTS	4	151			4	L=13 FT, A=2.0 IN2 + 20%	ALUMINUM	
STABILIZING STRUTS, FTGS, ETC	TBD	102			10	ESTIMATE		
THRUST STRUCT SEPARATION BOLTS	3	24			42			
LAUNCH ESC MOTOR / TURBOPUMP (JETT)			1410					
TURBOPUMP ASSEMBLY	2	1140			28	ESTIMATE		
ENGINE	1	250			-25	ESTIMATE		
ENGINE / TURBOPUMP MOUNT	1	20			10			
TURBOPUMP GAS GENERATOR (JETT)			360					
GAS GENERATOR	1	200			28	ESTIMATE		
GAS GENERATOR TANKAGE (WET)	1	160			28	ESTIMATE		
PROPELLANT SUPPLY (LES - JETT)			208					
LO2 SYSTEM - DISCONNECT	1	12			12	DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	114			4	DIA = 5.0 IN, L=20 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			12	DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	70			4	DIA = 5.0 IN, L=20 FT @ 3.5 LB/FT	ALUMINUM	
EQUIPMENT SUPPORT/INSTL - LES			198		12		10 % OF EQUIPMENT	
WEIGHT GROWTH MARGIN			376		15		15 % OF HARDWARE	
LES RESIDUALS			329			L= 20 FT EA @ 5.0 IN DIA		
GROSS WEIGHT				34502	104			
LAUNCH VEHICLE ADAPTER				1162	-35			
ADAPTER (STA.-70 TO STA. 0)			1010			S= 505 SF @ 2.0 PSF		
WEIGHT GROWTH MARGIN			152					
FWD FAIRING				536	239			
FWD FAIRING - NOSE CAP			466			S= 233 SF @ 2.0 PSF		
WEIGHT GROWTH MARGIN			70					
TOTAL LAUNCH WEIGHT				36200	99			

Table 21.3-2 Detailed Mass Properties for Configuration I (10 Persons) (Page 13 of 13)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE	XCG	REMARKS	WG%
SEQUENCED MASS DATA					
TOTAL WEIGHT		**36200**	**99**		
SEPARATE FROM LAUNCH VEH ADAPTER		-1162	-35		
ON-PAD ABORT WEIGHT		**35038**	**103**		
SEPARATE FWD FAIRING / NOSE CAP		-536	239		
JETTISON LAUNCH ESCAPE SYSTEM		-3210	104		
ON-ORBIT WEIGHT		**31293**	**101**		
DELETE CONSUMABLES TO REENTRY		-69	135		
DELETE POWER FLUIDS TO REENTRY		-263	127		
DELETE NOMINAL RCS ON-ORBIT PROP		-271	127		
SEPARATE OMS / RADIATOR MODULE		-8673	35		
BEGIN REENTRY WEIGHT		**22017**	**126**		
DELETE CONSUMABLES		-13	135		
DELETE REENTRY POWER FLUIDS		-5	127		
DELETE NOMINAL RCS REENTRY PROP		-105	127		
DEPLOY PARACHUTES		-794	190		
LANDING WEIGHT		**21101**	**124**		

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Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (1 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
PERSONNEL			6			
CREW		2				
PASSENGERS		4				
MISSION DURATION (DAYS)			3.0			
ECLSS						
CLOSURE LEVEL			OPEN			
PRESSURIZED VOLUME -CABIN (FT3)			655.0		60% vol. ratio, 71% area ratio	
PRESSURIZED VOLUME -AIRLOCK (FT3)			0.0			
PRESS/REPRESS EVENTS			2.0			
CABIN LEAKAGE (%VOLUME/DAY)			2.0			
PROPULSION		Delta V	Isp,sec			
RCS - H2O2/RP		146	310			
COLD GAS - N2		10	60			
OMS - LO2/RP		989	315			
LES - Expend Liquid Pusher		606	310			
ON-PAD ABORT WEIGHT			29428			
ON-ORBIT WEIGHT			25683			
LANDING WEIGHT			16435			
DESIGN LANDING WEIGHT			16000			
STRUCTURE - BODY GROUP				3969		15
FWD BODY BASIC STRUCTURE			662		ALUM SKIN / STR	
AFT BODY / HT SHIELD BASIC STRUCTURE			657		ALUM SKIN / STR	
FWD BODY SECONDARY STRUCTURE			343			
AFT BODY / HT SHIELD SECONDARY STRUCT			40			
CREW MODULE BASIC STRUCTURE			1293		ALUMINUM SKIN / STRINGER	
CREW MODULE SECONDARY STRUCTURE			974		ALUMINUM SKIN / STRINGER	
PROTECTION				1393		15
EXTERNAL TPS - BODY			1023			
INTERNAL INSULATION / TCS			288			
PURGE AND VENT SYSTEM			63		SCALED FROM SHUTTLE	
WINDOW / HATCH CONDITIONING			19		SCALED FROM SHUTTLE	
RECOVERY & AUXILIARY SYSTEMS				1240		15
PARACHUTE SYSTEM			1149			
DROGUE CHUTES	1	219				
BACKUP DROGUE	1	219				
MAIN CHUTE - BALLISTIC	4	606				
PARACHUTE SUPT/INSTL		104			10 % OF SYSTEM	
LANDING AND RECOVERY			12			
SEPARATION			79			

Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (2 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS) — NOTE: ALL MASS IN POUNDS

ITEM	QTY	VALUE			REMARKS		WG%
PROPULSION - REACTION CONTROL				**389**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
THRUSTER MODULES - FORWARD			97				
THRUSTERS - RCS	8	66					
THRUSTERS - COLD GAS	6	22			MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTER MODULE SUPPORT	4	9				10 % OF SYS	
THRUSTER MODULES - AFT			55				
THRUSTERS - RCS	6	50					
THRUSTERS - COLD GAS	0	0			ON RADIATOR MODULE		
THRUSTER MODULE SUPPORT	4	5				10 % OF SYS	
PRESSURIZATION SYSTEM			46				
GN2 BOTTLE(S) - RCS	2	14					
REGULATORS	2	9			FAIRCHILD		
FILL & DRAIN DISCONNECTS	1	1			PYRONETICS		
MANIFOLD/PLUMBING		7			BOEING		
TANK VENT / RELIEF		9					
PRESS SYS SUPPORT		6				15 % OF SYS	
PROPELLANT SUPPLY - RCS			174				
TANKAGE - H2O2	2	50				NEW	
TANKAGE - RP	2	18				NEW	
DISCONNECTS	2	2					
VALVES	9	35			CONSOLIDATED CONTROLS		
MANIFOLD/PLUMBING	1	28			BOEING 304L SS		
TANK FILL, VENT & DRAIN	2	25					
PROPELLANT SUPPLY SUPPORT		16				10 % OF SYS	
PROPELLANT SUPPLY - PROX-OPS (fixed)			17				
FLIGHT DISCONNECT	1	1			PYRONETICS		
MANIFOLD/PLUMBING		14			BOEING 304L SS		
COLD GAS SUPPLY SUPPORT		2				10 % OF SYS	

Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (3 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS) — NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			REMARKS	WG%
POWER - ELECTRICAL				2094		15
POWER SUPPLY			1300		FUEL CELL SYSTEM - 6 KW NOM, 9 KW PEAK TOTAL	
FUEL CELLS	2	361			Reduced Shuttle Cells - 2 of 3 to supply sustained power	
BATTERIES	6	432			Contingency only - 48 kw-hr LI-SOCL2	
O2 TANKAGE (EPS & ECLSS)	2	90			20.0 in ID VACUUM -JACKETED TANK	
H2 TANKAGE	2	94			24.0 in ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	4	12				
REACTANT RELIEF, VENT PLUMBING	4	64				
REACTANT SUPPLY PLUMBING	4	20				
REACTANT SUPPLY VALVES, DISC	4	12				
COOLANT PLUMBING		45			INCL. 30 LB FLUIDS	
WASTE WATER TANK		0			INCL IN WATER MANAGEMENT	
POWER SUPPLY SUPT/INSTL		170			15 % OF SYS	
POWER DIST EQUIP			169			
POWER DISTRIBUTION PANELS	3	99				
10VDC POWER SUPPLY	3	1				
EXTERIOR LIGHTS		15			ESTIMATE	
INTERIOR LIGHTS		20			ESTIMATE	
POWER DISTRIBUTION SUPT/INSTL		34			25 % OF SYS	
WIRING			625		ESTIMATE	
POWER DISTR. WIRE HARNESSES		350				
INSTRUMENTATION WIRING		100				
ELECTRICAL CONNECTORS		50			BULKHEAD FEEDTHRU PLATES	
HARNESS SUPT/INSTL		125			25 % OF SYS	

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Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (4 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			REMARKS	WG%
AVIONICS				**1587**		**15**
GUIDANCE, NAVIGATION AND CONTROL			184			
FAULT-TOLERANT NAVIGATOR	1	50				
GPS RECEIVER	2	12				
GPS ANTENNAS	2	10				
HORIZON SCANNER	2	12				
RADAR ALTIMETER	2	10				
RCS/ OMS VALVE DRIVER	2	90				
RENDEVOUS AND DOCK			133			
RENDEVOUS RADAR	1	30				
RADAR SIGNAL PROCESSOR	1	70				
ANTENNA	1	8				
ANTENNA MAST, DEPLOYMENT MECHS	1	25				
VEHICLE HEALTH MONITORING			75		SENSORS INCL IN INSTRUMENTATION COUNT	
MASS MEMORY	3	75				
COMMUNICATIONS AND TRACKING			238			
CENTRAL DATA FORMATTER	1	27				
TRANSPONDER	1	16				
POWER AMP	1	18				
DIPLEXER, RF SWITCH	1	3				
AUDIO	1	40				
UHF TRANSCEIVER	1	20				
ANTENNAS	3	24				
SEARCH AND RESCUE RADIO	1	40			ESTIMATED	
SIGNAL CABLING		50			ESTIMATED	
CONTROLS AND DISPLAYS			185			
RECONFIG DISPLAYS / CONTROL UNITS	5	50				
ELECTRONIC INTERFACES	3	75				
RECONFIG. PUSH-BUTTON PANEL	3	30				
RMS WORKSTATION	0	0			ESTIMATE FOR SERVICING MISSION	
HAND CONTROLLERS	2	30				
INSTRUMENTATION			83			
SENSOR INTERFACE UNIT (SIU)	60	30				
NETWORK INTERFACE UNIT (NIU)	2	3				
SENSORS, INSTRUMENTATION	700	50				
DATA HANDLING			463			
FAULT TOLERANT PROCESSOR	3	99				
MASS MEMORY	3	75				
DATA BUS COUPLERS	60	30			ESTIMATED	
MDM	7	259				
STRUCTURES/MECHS CONTROLS			82			
CHUTE CONTROLLER	1	61				
LASER FIRING UNIT	2	20				
LASER INITIATORS	5	1				
AVIONICS SUPT/INSTL			144		10 % OF AVIONICS	

Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (5 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
ENVIRONMENTAL CONTROL				**1311**		**15**
CABIN AND PERSONNEL SYSTEM			350			
O2 TANKAGE - CRYO STORAGE	0	0			INCL IN FUEL CELL REACTANT STORAGE	
O2 TANKAGE - (GAS FOR REPRESS)	1	15			Kevlar / Inconel	
N2 TANKAGE - (GAS FOR REPRESS)	2	58			Kevlar / Titanium	
PRESS PLUMBING		12				
CABIN PRESS & COMPOSITION CNTRLS		52			VALVES, VENT RELIEF VALVES, ETC	
CO2 REMOVAL - 2-BED LiOH		11			LiOH CANISTER UNIT - 2 CANISTER UNIT	
LiOH CANISTER STORAGE - NOMINAL		31			(7.0 LB/2-PERSON-DAY)	
LiOH CANISTER STORAGE - CONTING.		42			48-HR @(7.0 LB/2-PERSON-DAY)	
TEMP AND HUMIDITY CONTROL		102			FANS/SEPARATORS, HEAT EXCHANGER, ETC	
TRACE CONTAMINANT CONTROL		7			CANISTER FOR IMPURITY REMOVAL	
DUCTING, MISC		20			FANS INCLUDED IN TEMPERATURE CONTROL	
EQUIPMENT COOLING			209			
EQUIPMENT COLD PLATES		120			S= 60 SF @ 2.0 PSF	
AVIONICS COOLING ASSY		28			INCL HX, FANS, DUCTING	
IMU HEAT EXCHANGER ASSY	1	31				
PLUMBING		20				
DUCTING, MISC		10			FANS INCLUDED IN TEMPERATURE CONTROL	
HEAT TRANSFER WATER LOOP			141			
HEAT EXCHANGER - POTABLE WATER	1	17			BASED ON SHUTTLE	
PRIMARY, SECONDARY WATER PUMPS		78				
PLUMBING		21				
COOLANT IN LOOP - WATER		25				
HEAT TRANSFER FREON LOOP			270			
HEAT EXCHANGER - WATER-FREON	1	50			BASED ON SHUTTLE	
HEAT EXCHANGER - GSE	1	50			BASED ON SHUTTLE	
HEAT EXCHANGER - FUEL CELL	1	50			BASED ON SHUTTLE	
FREON PUMP PACKAGE	2	90				
COOLANT IN LOOP - FREON		30				
HEAT REJECTION			222			
AMMONIA BOILER ASSEMBLY		45			INCL AMMONIA TANK, HEAT EXCHNGR, VENT, VALVES	
COOLANT TANKAGE - WATER		14				
FLASH EVAPORATOR - WATER		58			FROM SHUTTLE	
TOPPING DUCT ASSEMBLY		78				
HIGH LOAD DUCT ASSEMBLY		27				
RADIATOR PANELS			0		INCL ON AFT ADAPTER	
ECLSS SUPT/INSTL			119		10 % OF ECLSS	

Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (6 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
PERSONNELPROVISIONS				978		15
FOOD MANAGEMENT			117			
GALLEY		0			GALLEY UNIT, WITH WATER DISPENSER	
FOOD STORAGE UNITS		117				
WATER MANAGEMENT			52			
WATER STORAGE TANK	2	17			FOR POTABLE WATER STORAGE	
HANDWASH - WET WIPES		2				
WATER DISPENSER		23			WATER DISPENSER ONLY	
PLUMBING, VALVES, ETC		10				
WASTE MANAGEMENT			47			
WASTE WATER TANK	2	17				
COMMODE SYSTEM		15			installation scar only for crew rotation	
EMERGENCY WASTE COLLECTION		15			SHUTTLE TYPE	
FIRE DETECTION / SUPPRESSION			13			
SMOKE DETECTORS		7				
FIRE SUPPRESSION TANK		6			INCLUDES SUPPRESSANT	
FURNISHINGS AND EQUIPMENT			660			
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SLEEP STATIONS		0			NOT REQUIRED FOR TRANSFER	
INCIDENTAL EQUIPMENT	6	60			STORAGE FOR ASTRONAUT PERSONAL EFFECTS	
SUPPORT/INSTALLATION			89		10 % OF ECLSS	
CREW MOD DRY, EXCL GROWTH				12961		15
WEIGHT GROWTH MARGIN				1944	15 % OF DRY WT	
CREW MODULE DRY WEIGHT				14905		

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Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (7 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
NON- CARGO ITEMS				2133		
CREW, WITH EQUIPMENT			1800			
FLIGHT CREW / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
TOOLS, MISCELLANEOUS	0	0				
EVA SUITS, WITH EXPENDABLES	0	0				
PROPELLANT RESIDUALS			64			
RCS RESIDUAL BI-PROP		46			RESIDUAL IN TANKS AND LINES	
RCS N2 PRESSURANT		18				
PROPELLANT RESERVES			269			
RCS RESERVES - BIPROP		269			20% OF NOMINAL PROPELLANT	
CREW MODULE INERT WEIGHT				17038		
NON- PROPELLANT				696		
IN-FLIGHT LOSSES			334			
FUEL CELL NOMINAL O2		238			0.71 LB/ KW -HR	
FUEL CELL NOMINAL H2		30			0.09 LB/ KW-HR	
FUEL CELL O2 RESERVES		48			20% NOMINAL	
FUEL CELL H2 RESERVES		6			20% NOMINAL	
FUEL CELL RESIDUAL REACTANT		13			ESTIMATE	
LIFE SUPPORT CONSUMABLES			362			
O2 - CRYO STORAGE		24			METABOLIC CONSUMPT. (2 LB/M-DAY) +20%	
O2 - GAS FOR REPRESSURIZATION		9			1 repress contingency + leak (0.38 LB/DAY)	
O2 - CABIN PRESSURIZATION		8				
N2 - GAS FOR REPRESS, LOSSES		40			1 repress contingency + leak (1.26 LB/DAY)	
N2 - CABIN PRESSURIZATION		38				
FOOD - nominal		40			4 LB/M-DAY	
FOOD - contingency		48			4 LB/M-DAY -- 48 hr contingency	
POTABLE WATER - nominal		0			4 LB/M-DAY supplied by fuel cells	
POTABLE WATER - contingency		55			4 LB/M-DAY --48 HR CONTINGENCY + resid	
EQUIP COOLING FLUIDS - AMMONIA		45			COOLANT FOR LAUNCH & REENTRY COOLING ONLY + 20 %	
EQUIP COOLING FLUIDS - WATER		55			COOLANT FOR ON-ORBIT HI-LOAD + 20 %	
PROPELLANT - NOMINAL				308		
RCS NOM PROPELLANT - BIPROP			308			
GROSS WEIGHT				18042		

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Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (8 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS		WG%
ADAPTER / RADIATOR MODULE				7641			
STRUCTURE			1338				
LAUNCH VEHICLE INTERFACE RING	1	316			L=86 FT, A=3.0 IN2	ALUMINUM	
CREW MODULE INTERFACE RING	1	170			L=56.6 FT, A=2.5 IN2	ALUMINUM	
MINOR FRAMES	2	256			L,AVE =71.3 FT, A=1.5 IN2	ALUMINUM	
LONGERONS	6	248			L=11.5 FT, A=3.0 IN2	ALUMINUM	
INTERMEDIATE STRUTS / FTGS	18	248			L ave=7.1 FT, A=1.0 IN2 +1.0 LB FTGS	ALUMINUM	
RADIATOR PANEL LINKAGE & HINGES	2	40					
LAUNCH / CREW MOD UMBIL PLATES	2	60					
THRUST STRUCTURE - OMS			367				
THRUST STRUTS	3	82			L=7.5 FT, A=2.5 IN2 +20%	ALUMINUM	
THRUST BEAMS	3	66			L=6.0 FT, A=2.5 IN2 +20%	ALUMINUM	
THRUST STR STABILIZING STRUTS	TBD	74					
ENG INTERFACE FTGS	3	9			ESTIMATE		
TANK SUPPORT STRUTS	8	56			L= 60 IN, A=1.0 IN2 + 1 LB FTGS EA	ALUMINUM	
TANK SWAY STRUTS	16	72			L=40 IN, A=1.0 IN2 + 1 LB FTG EA	ALUMINUM	
PRESS TANK SUPT FLANGES	8	8			ESTIMATE	ALUMINUM	
THERMAL PROTECTION			57		S= 834 SF, @ 0.0685 PSF	FOSR	
RCS THRUSTER MODULES			43				
THRUSTERS - RCS	2	17					
THRUSTERS - COLD GAS	6	22			MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTER MODULE SUPPORT	4	4				10 % OF SYS	
PROPELLANT SUPPLY - RCS			46				
DISCONNECTS	2	2					
MANIFOLD/PLUMBING	1	40			BOEING 304L SS		
PROPELLANT SUPPLY SUPPORT		4				10 % OF SYS	
PROPELLANT SUPPLY - PROX-OPS			476				
N2 BOTTLE(S) - OMS, COLD GAS	4	290				KEVLAR O/W Ti	
VALVES	16	82			CONSOLIDATED CONTROLS		
FLIGHT DISCONNECT	1	1			PYRONETICS		
FILL / DRAIN DISCONNECT	4	4			PYRONETICS		
MANIFOLD/PLUMBING		42			BOEING 304L SS		
TANK VENT / RELIEF		14					
COLD GAS SUPPLY SUPPORT		43				10 % OF SYS	
OMS THRUSTER MODULES			165				
ENGINES	3	150					
ENGINE MOUNT	3	15					
OMS PRESSURIZATION SYSTEM			62				
GN2 BOTTLES - OMS	0	0			INCL IN COLD GAS SYSTEM		
GAS VALVES	4	18			MOOG		
REGULATORS	2	9			FAIRCHILD		
FILL & DRAIN DISCONNECTS	2	2			PYRONETICS		
MANIFOLD/PLUMBING		10			BOEING 304L SS		
BOTTLE VENT / RELIEF		17			FAIRCHILD		
PRESS SYSTEM SUPPORT		6				15 % OF OMS	

Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (9 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE		REMARKS	WG%
PROPELLANT SUPPLY - OMS			305		
LO2 SYSTEM - TANK	2	85		ALUMINUM	
LO2 SYSTEM - VALVES	4	16			
LO2 SYSTEM - MANIFOLD	1	20		8 FT @ 2.5 LB/FT ALUMINUM	
LO2 SYSTEM - FILL, DRAIN, VENT	1	24			
LO2 SYSTEM - SUPPORT, INSTL		22		15 % OF OMS	
RP SYSTEM - TANK	2	60		ALUMINUM	
RP SYSTEM - VALVES	4	16			
RP SYSTEM - MANIFOLD	1	20		8 FT @ 2.5 LB/FT ALUMINUM	
RP SYSTEM - FILL, DRAIN, VENT	1	24			
RP SYSTEM - SUPPORT, INSTL		18		15 % OF OMS	
PROPELLANT SUPPLY (LES - OMS)			128		
LO2 SYSTEM - DISCONNECT	1	12		DIA=5.0 IN	
LO2 SYSTEM - VALVE	2	40		DIA=5.0 IN	
LO2 SYSTEM - MANIFOLD	1	17		DIA = 5.0 IN, L=3 FT @ 5.7 LB/FT ALUMINUM	
RP SYSTEM - DISCONNECT	1	12		DIA=5.0 IN	
RP SYSTEM - VALVE	2	40		DIA=5.0 IN	
RP SYSTEM - MANIFOLD	1	7		DIA = 5.0 IN, L=2 FT @ 3.5 LB/FT ALUMINUM	
POWER DISTRIBUTION			188		
WIRING, INCL GROUND UMBILICALS		150			
EQUIPMENT SUPPORT/INSTL		38		25 % OF WIRING	
ECLSS RADIATOR PANELS			564	ALUMINUM	
COOLANT IN PANELS - FREON		30			
FIXED PANELS	2	304		A=134 sf ea @ 1.14 psf ALUMINUM	
DEPLOYED PANELS	2	230		A=67 sf ea (67 sf ea side) @ 1.72 psf ALUMINUM	
OTHER - AUXILIARY SYSTEMS			174		
LAUNCH VEHICLE SEPARATION	6	90		EXPLOSIVE BOLT SEPARATION	
LAUNCH ESCAPE SEPARATION BOLTS	3	24			
CREW MODULE SEPARATION	6	60		EXPLOSIVE BOLT SEPARATION	
WEIGHT GROWTH MARGIN			587	15 % OF HARDWARE	
PROPELLANT RESIDUALS			242		
OMS RESIDUALS - IN TANKS		73		0.3 FT3 PER TANK	
OMS RESIDUALS - IN LINES, ENGINES		66		4 FT EA, 5.0 IN DIA.	
OMS PRESSURANTS		65		0.0251 LB/LB PROPELLANT NITROGEN	
COLD GAS RESIDUALS		38			
PROPELLANT RESERVES			412		
OMS RESERVES		236		10% OF NOMINAL	
RCS RESERVES - COLD GAS		176		20% OF NOMINAL PROPELLANT	
RCS NOM PROPELLANT - COLD GAS			126		
OMS NOMINAL PROPELLANT			2360	DELTA V AS SHOWN	

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Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (10 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS) — **NOTE: ALL MASS IN POUNDS**

ITEM	CREW ROTATION QTY	VALUE				REMARKS		WG%
LAUNCH ESCAPE SYS - JETTISONABLE				3210				
THRUST STRUCT. - LAUNCH ESCAPE (JETT)			329					
ENGINE THRUST STRUTS	3	52				L=4 FT, A=3.0 IN2 + 20%	ALUMINUM	
FEEDLINE STABILIZING STRUTS	4	151				L=13 FT, A=2.0 IN2 + 20%	ALUMINUM	
STABILIZING STRUTS, FTGS, ETC	TBD	102				ESTIMATE		
THRUST STRUCT SEPARATION BOLTS	3	24						
LAUNCH ESC MOTOR / TURBOPUMP (JETT)			1410					
TURBOPUMP ASSEMBLY	2	1140				ESTIMATE		
ENGINE	1	250				ESTIMATE		
ENGINE / TURBOPUMP MOUNT	1	20						
TURBOPUMP GAS GENERATOR (JETT)			360					
GAS GENERATOR	1	200				ESTIMATE		
GAS GENERATOR TANKAGE (WET)	1	160				ESTIMATE		
PROPELLANT SUPPLY (LES - JETT)			208					
LO2 SYSTEM - DISCONNECT	1	12				DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	114			4	DIA = 5.0 IN, L=20 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			12	DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	70			4	DIA = 5.0 IN, L=20 FT @ 3.5 LB/FT	ALUMINUM	
EQUIPMENT SUPPORT/INSTL - LES			198		12		10 % OF EQUIPMENT	
WEIGHT GROWTH MARGIN			376		1		15 % OF HARDWARE	
LES RESIDUALS			329			L= 20 FT EA @ 5.0 IN DIA		
GROSS WEIGHT				28893				
LAUNCH VEHICLE ADAPTER				1162				
ADAPTER (STA.-70 TO STA. 0)			1010			S= 505 SF @ 2.0 PSF		
WEIGHT GROWTH MARGIN			152					
FWD FAIRING				536				
FWD FAIRING - NOSE CAP			466			S= 233 SF @ 2.0 PSF		
WEIGHT GROWTH MARGIN			70					
TOTAL LAUNCH WEIGHT				30590				

Table 21.3-3 Detailed Mass Properties for Configuration I (6 Persons) (11 of 11 Pages)

GROUP WEIGHT STATEMENT
Low L/D PLS Concept #1 (6 Personnel, Tile TPS) — **NOTE: ALL MASS IN POUNDS**

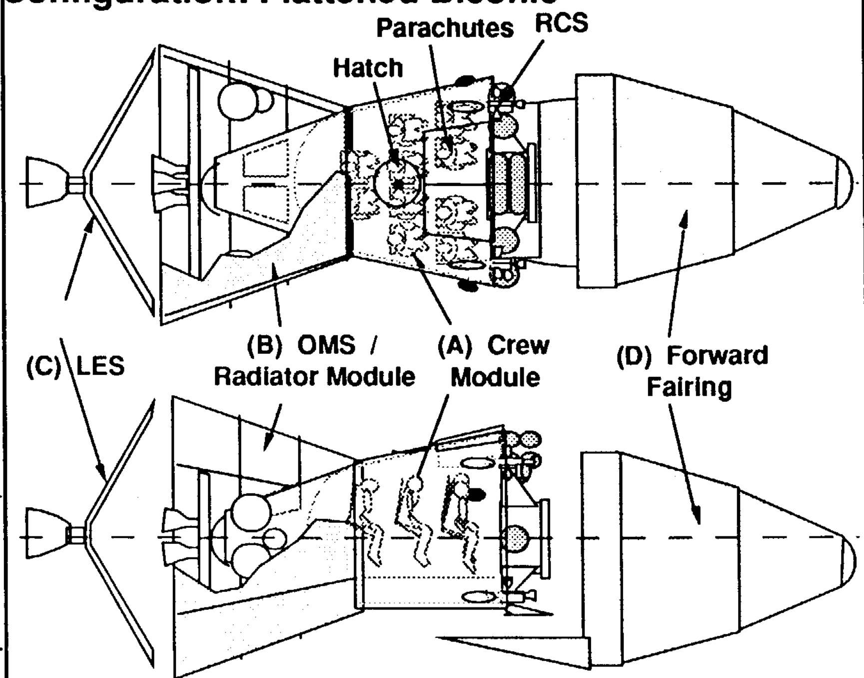
ITEM	CREW ROTATION QTY	VALUE		REMARKS	WG%
SEQUENCED MASS DATA					
TOTAL WEIGHT		**30590**			
SEPARATE FROM LAUNCH VEH ADAPTER		-1162			
ON-PAD ABORT WEIGHT		**29428**			
SEPARATE FWD FAIRING / NOSE CAP		-536			
JETTISON LAUNCH ESCAPE SYSTEM		-3210			
ON-ORBIT WEIGHT		**25683**			
DELETE CONSUMABLES TO REENTRY		-69			
DELETE POWER FLUIDS TO REENTRY		-263			
DELETE NOMINAL RCS ON-ORBIT PROP		-222			
SEPARATE OMS / RADIATOR MODULE		-7641			
BEGIN REENTRY WEIGHT		**17488**			
DELETE CONSUMABLES		-13			
DELETE REENTRY POWER FLUIDS		-5			
DELETE NOMINAL RCS REENTRY PROP		-86			
DEPLOY PARACHUTES		-949			
LANDING WEIGHT		**16435**			

Table 21.3-4 Summary Weight Statement - Configuration II

Crew / Passengers: 2 / 8 — Mission Duration : 72 Hour

Functional System	A	B	C	D
1. Structure	5116	1312	260	1747
2. Protection	1220	71		239
3. Propulsion	972	851	2220	
4. Power - Electrical	2157	188	40	
5. Control	121			
6. Avionics	1637			
7. Environment	1406	795		
8. Other - Personnel Provisions	1535			
Other - Landing, Aux Systems	2515	150	32	362
9. Weight Growth Margin	2502	505	383	352
Dry Mass	**19181**	**3872**	**2935**	**2700**
10. Non- Cargo (See Note 1)	3570	507	329	
11. Cargo	0	0		
Inert Mass	**22772**	**4379**	**3264**	**2700**
12. Non- Propellant Consumables	855			
13. Propellant - Nominal	551	2884		
Gross Mass	**24158**	**7263**	**3264**	**2700**
	31421		5964	
Total Mass	**37385**			

Configuration: Flattened Biconic



Notes:
A Crew Module
B OMS / Radiator Module
C Launch Escape System (LES)
D Fwd Fairing

All Mass in Pounds

1 Includes Flight Crew + Equipment (600 Lb), Passengers +Equip (2400 Lb), And Propellant Reserves / Residuals

Configuration II mass properties can be seen in summary and in detail as Tables 21.3-4 and 21.3-5 respectively. The six person version is summarized as Table 21.3-6.

Table 21.3-7 summarizes the weights for Configuration III, with details and assumptions found as Table 21.3-8. Table 21.3-9 is a summary of the downsized, six person version of Configuration III.

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 1 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE	XCG	REMARKS		WG%
PERSONNEL		10				
CREW		2				
PASSENGERS		8				
MISSION DURATION (DAYS)		3.0				
ECLSS						
CLOSURE LEVEL		OPEN				
PRESSURIZED VOLUME -CABIN (FT3)		980.0				
PRESSURIZED VOLUME -AIRLOCK (FT3)		0.0				
PRESS/REPRESS EVENTS		2.0				
CABIN LEAKAGE (%VOLUME/DAY)		2.0				
PROPULSION		Delta V Isp,sec				
RCS - H2O2/RP		146 310				
COLD GAS - N2		10 60				
OMS - LO2/RP		989 315				
LES - Expend Liquid Pusher		606 310				
ON-PAD ABORT WEIGHT		37384				
ON-ORBIT WEIGHT		31421				
LANDING WEIGHT		21607				
DESIGN LANDING WEIGHT		21500				
STRUCTURE - BODY GROUP		5116	171			15
FWD BODY		996				
BULKHEAD - STA 14	1	18	14	S= 8.73 SF @ 2.0 PSF		
MAJOR FRAME - STA 115	1	80	115	D,ave = 9.42 ft, A=3.0 in2	ALUMINUM	
MINOR FRAMES	4	82	65	L, ave = 8.5 ft, A=1.5 in2	ALUMINUM	
JOINTS, SPLICES, FASTENERS		27	65	15% OF FRAMES, BULKHEADS		
COVER PANELS, UPPER		116	75	S=68 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, LOWER		160	75	S=94 SF @ 1.7 PSF	ALUMINUM	
LONGERONS	6	126	65	L= 8.75 FT ea, A=2.0 IN2	ALUMINUM	
LANDING GEAR WELL & FRAMES		60	40	S=20 SF @ 3.0 PSF	ALUMINUM	
LANDING GEAR SUPT STRUTS	4	82	40	L= 8.5 FT, A=2.0 IN2		
LANDING GEAR DOOR - STRUCTURE	1	21	40	S= 6.0 SF @ 3.5 PSF	ALUMINUM	
LANDING GEAR DOOR - MECHANISM		38	40			
ACCESS PANELS	2	96	50	S= 16 SF EACH @3.0 PSF	ALUMINUM	
LAUNCH/PROP MODULE UMBIL PLATE	1	30	115			
EQUIPMENT SUPPORT RACKS		60	50	S= 30 SF @ 2.0 PSF	ALUMINUM	
MID/AFT BODY		1365				
MAJOR FRAME - STA 230		155	230	D, ave = 13.7 ft, A=3.0 in2	ALUMINUM	
MINOR FRAMES	3	200	173	L, ave=37.0 ft, A=1.5 in2	ALUMINUM	
JOINTS, SPLICES, FASTENERS		53	173	15% OF FRAMES, BULKHEADS		
COVER PANELS, UPPER		240	175	S=141 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, LOWER		307	175	S=180 SF @ 1.7 PSF	ALUMINUM	
LONGERONS	6	138	173	L=9.6 FT, A=2.0 IN2	ALUMINUM	
FTGS, CABIN ATTACHMENT	22	33	175			
WINDOW, THERMAL	2	14	210	S=0.8 SF EA @ 9.0 PSF		
WINDOW, RETAINER	2	5	210			
PARACHUTE COVER PANELS	2	72	200	S= 12 SF EACH @3.0 PSF	ALUMINUM	
PARACHUTE COVER ACTUATORS	4	16	200			
SERVICE MODULE UMBILICAL PLATE	1	20	260			
RMS GRAPPLE FITTING	2	44	235			
BODY FLAP CLOSEOUT/HINGE SUPT	1	68	230	S=7.5 SF @ 9.0 PSF		

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 2 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE) — **NOTE: ALL MASS IN POUNDS**

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PRESSURIZED CABIN			2476				ALUMINUM SKIN / STRINGER	
BULKHEAD, FWD	1	60			110	S=30 SF @ 2.0 PSF	ALUMINUM	
BULKHEAD, STA 226	1	330			226	S= 110 SF @ 3.0 PSF	ALUMINUM	
GUSSETS, AFT BULKHEAD	4	60			240	S= 20 SF TOTAL@ 3.0 PSF	ALUMINUM	
MINOR FRAMES, CABIN	3	175			173	L, ave= 32.4 FT , A= 1.5 IN2	ALUMINUM	
MINOR FRAMES, TUNNEL	2	45			248	L= 12.5 ft, A=1.5 In2	ALUMINUM	
COVER PANELS, UPPER		297			170	S=175 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, LOWER		322			170	S= 189 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, TUNNEL		54			248	S=36 SF @ 1.5 PSF	ALUMINUM	
PARTITION, STA 100	1	75			100	S= 63.2 SF, @ 1.2 PSF	COMPOSITE	
EQUIPMENT SUPPORT RACKS		150			95	S=100 SF @ 1.5 PSF		
FLOORING, EQUIP SUPT		184			173	S= 92 SF @ 2.0 PSF	ALUMINUM	
FTGS, CABIN ATTACHMENT	22	33			173			
LATERAL WINDOWS	2	43			210	S= 0.8 SF EA @ 27 PSF		
LATERAL WINDOWS, RETAINER	2	21			210			
AFT WINDOWS	2	43			226	S= 0.8 SF EA @ 27 PSF		
AFT WINDOWS, RETAINER	2	21			226			
DOCKING ADAPTER MECHANISM	1	340			263			
AIRLOCK INTERFACE RING	0	0			0	L= 13.0 FT, A= 2.5 IN2 + 20%	ALUMINUM	
TOP HATCH, STRUCTURE	1	58			150	36-IN DIA		
TOP HATCH, MECHANISM		32			150			
DOCKING HATCH, STRUCTURE	1	72			260	40-IN DIA, SHUTTLE-TYPE		
DOCKING HATCH, WINDOW & RETAINER	1	20			260			
DOCKING HATCH, MECHANISM		41			260			
BODY FLAP	1		279		250	S= 31 SF @ 9.0 PSF	RCC/ INSTL	
PROTECTION				1220	127			15
EXTERNAL TPS			919					
NOSE CAP, PANELS (ZONE 1)		65			10	S= 13.0 SF @ 5 PSF	RCC/INSTL	
NOSE CAP, INSTL HDWARE		39			14	60% OF RCC WEIGHT		
NOSE CAP, BULK INSULATION		53			14	S=8.8 SF @ 6.0 PSF		
BODY TPS, ZONE 2		161			75	S=61 SF @ 2.64 PSF	FRCI-12 w/SiC cover	
LANDING PAD DOOR TPS (ZONE 2)		17			75	S=6 SF @ 2.8 PSF, incl closeouts	FRCI-12 w/SiC cover	
BODY TPS, ZONE 3		399			175	S=283 SF @ 1.41 PSF	FRCI-12	
BODY TPS, ZONE 4		81			75	S=155 SF @ .522 PSF	Rigid TABI	
ACCESS PANEL TPS (ZONE 4)		17			175	S= 32 SF @ .522 PSF	Rigid TABI	
PARACHUTE COVER TPS (ZONE 4)		13			175	S=24 SF @ 0.522 PSF	Rigid TABI	
AFT BULKHEAD TPS, ZONE 5		74			230	S=184 SF @ 0.40 PSF	Rigid TABI	
INTERNAL INSULATION / TCS			220					
BULK INSULATION - FWD BODY		43			75	S= 124 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSULATION - FWD BODY		9			75	S= 124 SF @ 0.07 PSF	MLI	
BULK INSULATION - CABIN		140			175	S= 401 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSULATION - CABIN		28			175	S= 401 SF @ 0.07 PSF	MLI	
PURGE AND VENT SYSTEM			63			SCALED FROM SHUTTLE		
DUCTING		30			75			
VALVES		20			75			
SUPPORT, INSTALLATION		13			75			
WINDOW / HATCH CONDITIONING			19			SCALED FROM SHUTTLE		
PLUMBING		7			220			
DESSICANT, VALVES, DISCONNECTS		8			220			
SUPPORT, INSTALLATION		4			220			

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 3 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PROPULSION - REACTION CONTROL				**972**	**241**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
THRUSTER MODULES			196		235			
THRUSTERS - RCS	16	133						
THRUSTERS - COLD GAS	12	45				MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTER MODULE SUPPORT	4	18					10 % OF SYS	
PRESSURIZATION SYSTEM			66		240			
GN2 BOTTLE(S) - RCS	1	28				SCI 1270365 BOTTLE @ 4500 PSI	KEVLAR O/W Ti	
REGULATORS	2	9				FAIRCHILD		
FILL & DRAIN DISCONNECTS	1	1				PYRONETICS		
MANIFOLD/PLUMBING		10				BOEING		
TANK VENT / RELIEF		9						
PRESS SYS SUPPORT		9					15 % OF SYS	
PROPELLANT SUPPLY - RCS			193		240			
TANKAGE - H2O2	2	60						
TANKAGE - RP	1	15						
VALVES	9	35				CONSOLIDATED CONTROLS		
MANIFOLD/PLUMBING	1	40				BOEING 304L SS		
TANK FILL, VENT & DRAIN	2	25						
PROPELLANT SUPPLY SUPPORT		18					10 % OF SYS	
PROPELLANT SUPPLY - PROX OPS (fixed)			36		245			
FLIGHT DISCONNECTS	1	1				PYRONETICS		
MANIFOLD/PLUMBING		32				BOEING 304L SS		
COLD GAS SUPPLY SUPPORT		3					10 % OF SYS	
PROPELLANT SUPPLY - PROX-OPS (expend)			481					
N2 BOTTLE(S) - COLD GAS	4	310			250	BRUNSWICK 220064, (26.3 IN ID)	KEVLAR O/W Ti	
VALVES	16	82			230	CONSOLIDATED CONTROLS		
FLIGHT DISCONNECT	1	1			230	PYRONETICS		
FILL / DRAIN DISCONNECT	4	4			250	PYRONETICS		
MANIFOLD/PLUMBING		10			230	BOEING 304L SS		
TANK VENT / RELIEF		14			250			
TANK SEPARATION	4	16			230	EXPLOSIVE BOLTS		
COLD GAS SUPPLY SUPPORT		44			230		10 % OF SYS	

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 4 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE)
NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
POWER - ELECTRICAL				**2157**	**62**		**15**
POWER SUPPLY			1300			FUEL CELL SYSTEM - 6 KW NOM, 9 KW PEAK TOTAL	
FUEL CELLS	2	361			45	Reduced Shuttle Cells - 2 of 3 to supply sustained power	
BATTERIES	6	432			25	Contingency only - 48 kw-hr LI-SOCL2	
O2 TANKAGE (EPS & ECLSS)	2	90			70	20.0 in ID VACUUM -JACKETED TANK	
H2 TANKAGE	2	94			70	24.0 in ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	4	12			70		
REACTANT RELIEF, VENT PLUMBING	4	64			70		
REACTANT SUPPLY PLUMBING	4	20			60		
REACTANT SUPPLY VALVES, DISC	4	12			60		
COOLANT PLUMBING		45			55	INCL. 30 LB FLUIDS	
POWER SUPPLY SUPT/INSTL		170			60	15 % OF SYS	
POWER DIST EQUIP			169				
POWER DISTRIBUTION PANELS	3	99			45		
10VDC POWER SUPPLY	3	1			45		
EXTERIOR LIGHTS		15			230	ESTIMATE	
INTERIOR LIGHTS		20			150	ESTIMATE	
POWER DISTRIBUTION SUPT/INSTL		34			100	25 % OF SYS	
WIRING			688			ESTIMATE	
POWER DISTR. WIRE HARNESSES		400			95		
INSTRUMENTATION WIRING		100			40		
ELECTRICAL CONNECTORS		50			95	BULKHEAD FEEDTHRU PLATES	
HARNESS SUPT/INSTL		138			90	25 % OF SYS	
SURFACE CONTROLS				121	240		15
BODY FLAP ACTUATION			121			DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110			240		
ACTUATOR SUPT/INSTL		11			240	10 % OF SYS	

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 5 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE) — **NOTE: ALL MASS IN POUNDS**

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
AVIONICS				**1637**	**127**		**15**
GUIDANCE, NAVIGATION AND CONTROL			229				
FAULT-TOLERANT NAVIGATOR	1	50			95		
GPS RECEIVER	2	12			95		
GPS ANTENNAS	2	10			240		
HORIZON SCANNER	2	12			240		
RADAR ALTIMETER	2	10			240		
BODY FLAP DRIVER	1	45			230		
RCS/ OMS VALVE DRIVER	2	90			95		
RENDEVOUS AND DOCK			133				
RENDEVOUS RADAR	1	30			235		
RADAR SIGNAL PROCESSOR	1	70			200		
ANTENNA	1	8			235		
ANTENNA MAST, DEPLOYMENT MECHS	1	25			235		
VEHICLE HEALTH MONITORING			75			SENSORS INCL IN INSTRUMENTATION COUNT	
MASS MEMORY	3	75			40		
COMMUNICATIONS AND TRACKING			238		95		
CENTRAL DATA FORMATTER	1	27					
TRANSPONDER	1	16					
POWER AMP	1	18					
DIPLEXER, RF SWITCH	1	3					
AUDIO	1	40					
UHF TRANSCEIVER	1	20					
ANTENNAS	3	24					
SEARCH AND RESCUE RADIO	1	40				ESTIMATED	
SIGNAL CABLING		50				ESTIMATED	
CONTROLS AND DISPLAYS			185		210		
RECONFIG DISPLAYS / CONTROL UNITS	5	50					
ELECTRONIC INTERFACES	3	75					
RECONFIG. PUSH-BUTTON PANEL	3	30					
RMS WORKSTATION	0	0				ESTIMATE FOR SERVICING MISSION	
HAND CONTROLLERS	2	30					
INSTRUMENTATION			83		40		
SENSOR INTERFACE UNIT (SIU)	60	30					
NETWORK INTERFACE UNIT (NIU)	2	3					
SENSORS, INSTRUMENTATION	700	50					
DATA HANDLING			463		95		
FAULT TOLERANT PROCESSOR	3	99					
MASS MEMORY	3	75					
DATA BUS COUPLERS	60	30				ESTIMATED	
MDM	7	259					
STRUCTURES/MECHS CONTROLS			82				
CHUTE, LANDING GEAR CONTROLLER	1	61			200		
LASER FIRING UNIT	2	20			95		
LASER INITIATORS	5	1			95		
AVIONICS SUPT/INSTL			149		134	10 % OF AVIONICS	

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 6 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE)
NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			XCG	REMARKS	WG%
ENVIRONMENTAL CONTROL				**1406**	**104**		**15**
CABIN AND PERSONNEL SYSTEM			416				
O2 TANKAGE - CRYO STORAGE	0	0				INCL IN FUEL CELL REACTANT STORAGE	
O2 TANKAGE - (GAS FOR REPRESS)	1	15			200	Kevlar / Inconel	
N2 TANKAGE - (GAS FOR REPRESS)	2	60			200	Kevlar / Titanium	
PRESS PLUMBING		12			190		
CABIN PRESS & COMPOSITION CNTRLS		65			170	VALVES, VENT RELIEF VALVES, ETC	
CO2 REMOVAL - 2-BED LiOH		11			130	LiOH CANISTER UNIT - 2 CANISTER UNIT	
LiOH CANISTER STORAGE		100			100	(20 / 28 M-DAY)	
TEMP AND HUMIDITY CONTROL		127			110	FANS/SEPARATORS, HEAT EXCHANGER, ETC	
TRACE CONTAMINANT CONTROL		7			130	CANISTER FOR IMPURITY REMOVAL	
DUCTING, MISC		20			130	FANS INCLUDED IN TEMPERATURE CONTROL	
EQUIPMENT COOLING			209				
EQUIPMENT COLD PLATES		120			95	S= 60 SF @ 2.0 PSF	
AVIONICS COOLING ASSY		28			95	INCL HX, FANS, DUCTING	
IMU HEAT EXCHANGER ASSY	1	31			95		
PLUMBING		20			95		
DUCTING, MISC		10			95	FANS INCLUDED IN TEMPERATURE CONTROL	
HEAT TRANSFER WATER LOOP			161				
HEAT EXCHANGER - POTABLE WATER	1	17			100	BASED ON SHUTTLE	
PRIMARY, SECONDARY WATER PUMPS		78			100		
PLUMBING		30			100		
COOLANT IN LOOP - WATER		36			100		
HEAT TRANSFER FREON LOOP			270				
HEAT EXCHANGER - WATER-FREON	1	50			90	BASED ON SHUTTLE	
HEAT EXCHANGER - GSE	1	50			90	BASED ON SHUTTLE	
HEAT EXCHANGER - FUEL CELL	1	50			45	BASED ON SHUTTLE	
FREON PUMP PACKAGE	2	90			90		
COOLANT IN LOOP - FREON		30			90		
HEAT REJECTION			222				
AMMONIA BOILER ASSEMBLY		45			40	INCL AMMONIA TANK, HEAT EXCHNGR, VENT, VALVES	
COOLANT TANKAGE - WATER		14			90		
FLASH EVAPORATOR - WATER		58			80	FROM SHUTTLE	
TOPPING DUCT ASSEMBLY		78			100		
HIGH LOAD DUCT ASSEMBLY		27			100		
RADIATOR PANELS			0			INCL ON PROPULSION MODULE	
ECLSS SUPT/INSTL			128		104	10 % OF ECLSS	

Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 7 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE		XCG	REMARKS	WG%
OTHER - PERSONNELPROVISIONS				**1535**	**150**		**15**
FOOD MANAGEMENT			117			
GALLEY		0		130	GALLEY UNIT, WITH WATER DISPENSER	
FOOD STORAGE UNITS		117		150		
WATER MANAGEMENT			85	100		
WATER STORAGE TANK		50			FOR POTABLE WATER STORAGE	
HANDWASH - WET WIPES		2				
WATER DISPENSER		23			WATER DISPENSER ONLY	
PLUMBING, VALVES, ETC		10				
WASTE MANAGEMENT			80	115		
WASTE WATER TANK		50				
COMMODE SYSTEM		15			installation scar only for crew rotation	
EMERGENCY WASTE COLLECTION		15			SHUTTLE TYPE	
FIRE DETECTION / SUPPRESSION			13	100		
SMOKE DETECTORS		7				
FIRE SUPPRESSION TANK		6			INCLUDES SUPPRESSANT	
FURNISHINGS AND EQUIPMENT			1100			
SEATS, PERSONNEL RESTRAINTS	4	400		190	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	4	400		150	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200		110	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SLEEP STATIONS		0			NOT REQUIRED FOR TRANSFER	
INCIDENTAL EQUIPMENT	10	100		150	STORAGE FOR ASTRONAUT PERSONAL EFFECTS	
SUPPORT/INSTALLATION			140	152	10 % OF ECLSS	
OTHER - RECOVERY & AUXILIARY			**2515**	**194**		**15**
PARACHUTE SYSTEM			1720			
DROGUE CHUTES	1	289		200	12 + 0.00423 LB/LB INFLATION LOAD x 3g (MAX)	
BACKUP DROGUE	1	289		200		
MAIN CHUTE - HI-GLIDE	1	443		200	0.020 LB/LB INFLATION LOAD (MAX) @ 22 FPS	
BACKUP CHUTES - HI-GLIDE	1	443		200		
PARACHUTE CNTRL SPINDLE, MOTORS	2	100		200	ESTIMATE	
PARACHUTE SUPT/INSTL		156		200	10 % OF SYSTEM	
LANDING SYSTEM			605			
NOSE LANDING GEAR	1	108		40	0.005 LB/LB DESIGN LANDING WT (MAX)	
AFT LANDING GEAR	2	430		220	0.02 LB/LB DESIGN LANDING WT (MAX)	
FLOTATION COLLAR AIRBAGS	4	12		240		
LANDING GEAR SUPT/INSTL		55		202	10 % OF SYSTEM	
SATELLITE SERVICE MODIFICATIONS			0			
LARGE RMS	0	0				
SMALL RMS	0	0				
TOOLS, MISCELLANEOUS	0	0				
EVA SUITS, WITH EXPENDABLES	0	0				
SEPARATION			190			
PARACHUTE COVERS SEPARATION	2	40		200	L=20 FT @ 2.0 LB/FT	
FWD FAIRING SEPARATION		60		230	L=20 FT @ 2.0 LB/FT	
LAUNCH VEHICLE SEP BOLTS	6	90		115		
CREW MOD DRY, EXCL GROWTH			**16679**	**150**		**15**
WEIGHT GROWTH MARGIN			**2502**	**150**	**15 % OF DRY WT**	

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 8 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
CREW MODULE DRY WEIGHT				**19181**	**150**		
NON- CARGO ITEMS				**3570**	**173**		
CREW, WITH EQUIPMENT			3000				
FLIGHT CREW / personal effects	2	600			200	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			190	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	4	1200			150	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			110	90TH PERCENTILE + 107 lb ea.	
PROPELLANT RESIDUALS			101				
RCS RESIDUAL BI-PROP		42			235	RESIDUAL IN TANKS AND LINES	
RCS N2 PRESSURANT		17			235		
COLD GAS RESIDUALS		42			250		
PROPELLANT RESERVES			469				
RCS RESERVES - BIPROP		256			240	20% OF NOMINAL PROPELLANT	
RCS RESERVES - COLD GAS		213			250	20% OF NOMINAL PROPELLANT	
PAYLOAD / CARGO				**0**		**NO CARGO CAPABILITY**	
CREW MODULE INERT WEIGHT				**22751**	**153**		
NON- PROPELLANT				855	112		
IN-FLIGHT LOSSES			334			(CR- 264 KW-HR; SS- 840 KW-HR)	
FUEL CELL NOMINAL O2		238			70	0.71 LB/ KW -HR	
FUEL CELL NOMINAL H2		30			70	0.09 LB/ KW-HR	
FUEL CELL O2 RESERVES		48			70	20% NOMINAL	
FUEL CELL H2 RESERVES		6			70	20% NOMINAL	
FUEL CELL RESIDUAL REACTANT		13			70	ESTIMATE	
LIFE SUPPORT CONSUMABLES			521				
O2 - CRYO STORAGE		34			70	METABOLIC CONSUMPT. (2 LB/M-DAY) +20%+LEAKAGE	
O2 - GAS FOR REPRESSURIZATION		15			200	LEAK (0.38 LB/DAY)	
O2 - CABIN PRESSURIZATION		14			200		
N2 - GAS FOR REPRESS, LOSSES		67			200	LEAK (1.26 LB/DAY)	
N2 - CABIN PRESSURIZATION		63			200		
FOOD - NOMINAL		56			150	4 LB/M-DAY	
FOOD - CONTINGENCY		80			150	4 LB/M-DAY - 48 HR CONTINGENCY	
POTABLE WATER - NOMINAL		0			100	4 LB/M-DAY - SUPPLIED BY FUEL CELLS	
POTABLE WATER - CONTINGENCY		92			100	4 LB/M-DAY --48 HR CONTINGENCY	
EQUIP COOLING FLUIDS - ammonia		45			90	COOLANT FOR LAUNCH & REENTRY COOLING ONLY + 20 %	
EQUIP COOLING FLUIDS - water		55			90	WATER FOR HI-LOAD REJECTION + 20 %	
PROPELLANT - NOMINAL				**551**	**243**		
RCS NOM PROPELLANT - BIPROP			398		240		
RCS NOM PROPELLANT - COLD GAS			152		250		
OMS FLUIDS			0			INCL IN JETTISONABLE OMS POD	
GROSS WEIGHT, LESS OMS				**24158**	**154**		

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 9 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE) — NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PROPULSION / RADIATOR MODULE				**3872**	**35**			
STRUCTURE			1312					
AFT ADAPTER INTERFACE RING	1	158			-20	L=43 FT, A=3.0 IN2	ALUMINUM	
CREW MODULE INTERFACE RING	1	92			115	L=30.6 FT, A=2.5 IN2	ALUMINUM	
MINOR FRAMES	2	134			48	L=37.3 FT, A=1.5 IN2	ALUMINUM	
LONGERONS	6	257			48	L=11.9 FT, A=3.0 IN2	ALUMINUM	
INTERMEDIATE STRUTS / FTGS	18	248			48	L ave=7.1 FT, A=1.0 IN2 +1.0 LB FTGS	ALUMINUM	
RADIATOR PANEL LINKAGE & HINGES	2	40			48			
LAUNCH / CREW MOD UMBIL PLATES	2	60			48			
THRUST STRUCTURE	1	95			-5	L=22 FT, A=3.0 IN2 +20%	ALUMINUM	
THRUST STR STABILIZING STRUTS	6	48			-5			
THRUST RING / FTGS	1	25			-5	D=40 IN, A=2.0 IN2	ALUMINUM	
ENG INTERFACE FTGS	3	9			-7	ESTIMATE		
TANK SUPPORT STRUTS	8	66			39	L= 72 IN, A=1.0 IN2 + 1 LB FTGS EA	ALUMINUM	
TANK SWAY STRUTS	16	72			39	L=40 IN, A=1.0 IN2 + 1 LB FTG EA	ALUMINUM	
PRESS TANK SUPT FLANGES	8	8			22	ESTIMATE	ALUMINUM	
THERMAL PROTECTION			71		50	S= 1034 SF, @ 0.0685 PSF	FOSR	
PROPULSION - OMS			851			LO2/RP SYSTEM; EXTERNAL PRESS		
ENGINES	3	150			-13			
ENGINE MOUNT	3	15			-3			
LO2 SYSTEM - TANK	2	93			39	41.0 in ID TANK, WITH INSULATION	ALUMINUM	
LO2 SYSTEM - VALVES	6	24			4			
LO2 SYSTEM - MANIFOLD	1	28			8	4 FT @ 5.8 LB/FT + 5 FT @ 1 LB/FT	ALUMINUM	
LO2 SYSTEM - LES VALVES	1	20			-10			
LO2 SYSTEM - LES DISCONNECT	1	12			-30			
LO2 SYSTEM - FILL, DRAIN, VENT	1	24			39			
LO2 SYSTEM - SUPPORT, INSTL		30			39		15 % OF OMS	
RP SYSTEM - TANK	2	115			39	35.0 in ID TANK, WITH INSULATION	ALUMINUM	
RP SYSTEM - VALVES	6	24			4			
RP SYSTEM - MANIFOLD	1	19			8	4 FT @ 3.5 LB/FT + 5.0 FT @ 1 LB/FT	ALUMINUM	
RP SYSTEM - LES VALVES	1	20			-10			
RP SYSTEM - LES DISCONNECT	1	12			-30			
RP SYSTEM - FILL, DRAIN, VENT	1	24			39			
RP SYSTEM - SUPPORT, INSTL		32			39		15 % OF OMS	
GN2 BOTTLES - OMS	2	128			22	SCI 1270365 , 4500 PSI		
GAS VALVES	4	18			8	MOOG		
REGULATORS	2	9			8	FAIRCHILD		
FILL & DRAIN DISCONNECTS	2	2			22	PYRONETICS		
MANIFOLD/PLUMBING		10			8	BOEING 304L SS		
BOTTLE VENT / RELIEF		17			22	FAIRCHILD		
PRESS SYSTEM SUPPORT		25			8		15 % OF OMS	
POWER DISTRIBUTION			188		48			
WIRING, INCL GROUND UMBILICALS		150						
EQUIPMENT SUPPORT/INSTL		38					25 % OF WIRING	
ECLSS RADIATOR PANELS			795		50		ALUMINUM	
COOLANT IN PANELS - FREON		30						
FIXED PANELS	2	304				A=134 sf ea @ 1.14 psf	ALUMINUM	
DEPLOYED PANELS	2	461				A=134 sf ea (134 sf ea side) @ 1.72 psf	ALUMINUM	
OTHER - AUXILIARY SYSTEMS			150					
LAUNCH VEHICLE SEPARATION	6	90			-26	EXPLOSIVE BOLT SEPARATION		
CREW MODULE SEPARATION	6	60			115	EXPLOSIVE BOLT SEPARATION		
WEIGHT GROWTH MARGIN			505		35		15 % OF HARDWARE	

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 10 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE) — NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
OMS PROPELLANTS				**3391**	**39**			
OMS RESIDUALS			219		39			
RESIDUALS - IN TANKS		73				0.3 FT3 PER TANK		
RESIDUALS - IN LINES, ENGINES		66				4 FT EA, 5.0 IN DIA.		
PRESSURANTS		80				0.0251 LB/LB PROPELLANT	NITROGEN	
OMS RESERVES			288		39			
RESERVE PROPELLANT		288				10% OF NOMINAL		
OMS NOMINAL PROPELLANT			2884		39	DELTA V AS SHOWN		
ON-ORBIT GROSS WEIGHT				**31421**	**127**			
LAUNCH VEHICLE ADAPTER				**1956**	**-79**			
STRUCTURE			1363		-79	S= 545 SF @ 2.5 PSF	ALUM SKIN/STR	
PROTECTION - THERMAL			0		-79			
POWER - WIRE HARNESS			188		-79	L= 8 FT, INCL CONNECTORS, ETC		
OTHER - CREW MOD SEPARATION SYS	6		150		-79	SEP BOLTS		
WEIGHT GROWTH MARGIN			255		-79	15 % OF HARDWARE		
FORWARD FAIRING				**2700**	**315**			
STRUCTURE			1747					
FAIRING NOSE CAP		45			504	S= 15 SF @ 3.0 PSF		
FAIRING - CONIC SECTION		1148			348	S= 574 SF @ 2.0 PSF	AL SKIN/STRNGR	
FAIRING - CYLINDRICAL SECTION		444			250	S= 222 SF @ 2.0 PSF	AL SKIN/STRNGR	
FAIRING - FLAT SECTION COVER		110			250	S= 55 SF @ 2.0 PSF	AL SKIN/STRNGR	
PROTECTION - THERMAL			239		348	S=796 SF @ 0.3 PSF	SPRAY-ON FOAM	
OTHER - AUXILIARY SYS			362					
SEPARATION JOINTS		212			230	L= 106 FT @ 2.0 LB/FT	SUPER-ZIP	
SEPARATION SPRINGS/FTGS		150			230	ESTIMATE		
WEIGHT GROWTH MARGIN			352		348	15 % OF HARDWARE		
BALLAST				**0**	**0**			
FWD NOSE BALLAST			0		900			

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Table 21.3-5 Detailed Mass Properties for Configuration II (10 Persons) (Page 11 of 11)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (10 PERSONNEL SIZE) — NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
EXPENDABLE LAUNCH ESCAPE SYSTEM				**3264**	**-50**		
STRUCTURE			260				
ENGINE THRUST STRUCTURE		173			-42	L=30 FT, A=4.0 IN2 + 20% ALUMINUM	
STABILIZING STRUTS, FTGS, ETC		87			-42	ESTIMATE	
PROPULSION - LIQUID LES			2220				
TURBOPUMP ASSEMBLY	1	1140			-66		
ENGINE	1	250			-88		
ENGINE / TURBOPUMP MOUNT	1	20			-60		
GAS GENERATOR	1	200			-60		
GAS GENERATOR TANKAGE (WET)	1	160			-60		
LO2 SYSTEM - DISCONNECT	1	12			-33	DIA=5.0 IN	
LO2 SYSTEM - VALVE	1	20			-48	DIA=5.0 IN	
LO2 SYSTEM - MANIFOLD	1	114			-53	DIA = 5.0 IN, L=20 FT @ 5.7 LB/FT ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			-33	DIA=5.0 IN	
RP SYSTEM - VALVE	1	20			-48	DIA=5.0 IN	
RP SYSTEM - MANIFOLD	1	70			-53	DIA = 5.0 IN, L=20 FT @ 3.5 LB/FT ALUMINUM	
EQUIPMENT SUPPORT/INSTL		202				10 % OF EQUIPMENT	
POWER - WIRE HARNESS			40		-42	SCALED FROM APOLLO	
OTHER - SEPARATION BOLTS	4		32		0		
WEIGHT GROWTH MARGIN			383		-45	15 % OF HARDWARE	
OMS RESIDUALS - IN LINES			329			20 FT EA @ 5.0 IN DIA	
TOTAL LAUNCH WEIGHT				39340	115		

SEQUENCED MASS DATA

ITEM	QTY	VALUE	XCG	REMARKS	WG%
TOTAL WEIGHT		39340	115		
SEPARATE FROM LAUNCH VEH ADAPTER		-1956	-79		
ON-PAD ABORT WEIGHT		37384	125		
ON-ORBIT WEIGHT		31421	127		
DELETE CONSUMABLES TO REENTRY		-62	140		
DELETE POWER FLUIDS TO REENTRY		-258	70		
DELETE NOMINAL RCS ON-ORBIT PROP		-297	240		
DELETE ALL PROX OPS COLD GAS		-408	250		
DELETE ALL OMS ON-ORBIT PROP		-3391	39		
SEPARATE PROX-OPS TANKS		-554	244		
SEPARATE OMS POD		-3872	35		
BEGIN REENTRY WEIGHT		22579	150		
DELETE CONSUMABLES		-19	140		
DELETE REENTRY POWER FLUIDS		-10	70		
DELETE NOMINAL RCS REENTRY PROP		-102	240		
DEPLOY PARACHUTES		-842	200		
LANDING WEIGHT		21607	148		

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Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 1 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE) **NOTE: ALL MASS IN POUNDS**

ITEM	QTY	CREW ROTATION VALUE			REMARKS	WG%
PERSONNEL			6			
CREW		2				
PASSENGERS		4				
MISSION DURATION (DAYS)			3.0			
ECLSS						
CLOSURE LEVEL			OPEN			
PRESSURIZED VOLUME -CABIN (FT3)			588.0		60% VOLUME, 71% AREA RATIO	
PRESSURIZED VOLUME -AIRLOCK (FT3)			0.0			
PRESS/REPRESS EVENTS			2.0			
CABIN LEAKAGE (%VOLUME/DAY)			2.0			
PROPULSION		Delta V	Isp,sec			
RCS - H2O2/RP		146	310			
COLD GAS - N2		10	60			
OMS - LO2/RP		989	315			
LES - Expend Liquid Pusher		606	310			
ON-PAD ABORT WEIGHT			31655			
ON-ORBIT WEIGHT			25691			
LANDING WEIGHT			17185			
DESIGN LANDING WEIGHT			17200			
STRUCTURE - BODY GROUP				3901		15
FWD BODY			707			
MID/AFT BODY			1028			
SKIN PANELS		776			ALUMINUM	
FTGS, CABIN ATTACHMENT	22	33				
WINDOW, THERMAL	2	14			S=0.8 SF EA @ 9.0 PSF	
WINDOW, RETAINER	2	5				
PARACHUTE COVER PANELS	2	72			S= 12 SF EACH @3.0 PSF ALUMINUM	
PARACHUTE COVER ACTUATORS	4	16				
SERVICE MODULE UMBILICAL PLATE	1	20				
RMS GRAPPLE FITTING	2	44				
BODY FLAP CLOSEOUT/HINGE SUPT	1	48				
PRESSURIZED CABIN			1968		ALUMINUM SKIN / STRINGER	
SKIN PANELS, BULKHEADS	1	1244			ALUMINUM	
FTGS, CABIN ATTACHMENT	22	33				
LATERAL WINDOWS	2	43			S= 0.8 SF EA @ 27 PSF	
LATERAL WINDOWS, RETAINER	2	21				
AFT WINDOWS	2	43			S= 0.8 SF EA @ 27 PSF	
AFT WINDOWS, RETAINER	2	21				
DOCKING ADAPTER MECHANISM	1	340				
AIRLOCK INTERFACE RING	0	0			L= 13.0 FT, A= 2.5 IN2 + 20% ALUMINUM	
TOP HATCH, STRUCTURE	1	58			36-IN DIA	
TOP HATCH, MECHANISM		32				
DOCKING HATCH, STRUCTURE	1	72			40-IN DIA, SHUTTLE-TYPE	
DOCKING HATCH, WINDOW & RETAINER	1	20				
DOCKING HATCH, MECHANISM		41				
BODY FLAP	1		198		RCC/ INSTL	

Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 2 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
PROTECTION				**878**		**15**
EXTERNAL TPS			652			
INTERNAL INSULATION / TCS			156			
PURGE AND VENT SYSTEM			51		SCALED FROM SHUTTLE	
DUCTING		21				
VALVES		20				
SUPPORT, INSTALLATION		10				
WINDOW / HATCH CONDITIONING			19		SCALED FROM SHUTTLE	
PLUMBING		7				
DESSICANT, VALVES, DISCONNECTS		8				
SUPPORT, INSTALLATION		4				
PROPULSION - REACTION CONTROL				**850**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**	**15**
THRUSTER MODULES			196			
THRUSTERS - RCS	16	133				
THRUSTERS - COLD GAS	12	45			MOOG 5264 - 30 LBF N2 THRUSTERS	
THRUSTER MODULE SUPPORT	4	18			10 % OF SYS	
PRESSURIZATION SYSTEM			48			
GN2 BOTTLE(S) - RCS	1	22			SCI 1270365 BOTTLE @ 4500 PSI KEVLAR O/W Ti	
REGULATORS	2	9			FAIRCHILD	
FILL & DRAIN DISCONNECTS	1	1			PYRONETICS	
MANIFOLD/PLUMBING		1			BOEING	
TANK VENT / RELIEF		9				
PRESS SYS SUPPORT		6			15 % OF SYS	
PROPELLANT SUPPLY - RCS			166			
TANKAGE - H2O2	2	48				
TANKAGE - RP	1	12				
VALVES	9	35			CONSOLIDATED CONTROLS	
MANIFOLD/PLUMBING	1	31			BOEING 304L SS	
TANK FILL, VENT & DRAIN	2	25				
PROPELLANT SUPPLY SUPPORT		15			10 % OF SYS	
PROPELLANT SUPPLY - PROX OPS (fixed)			30			
FLIGHT DISCONNECTS	1	1			PYRONETICS	
MANIFOLD/PLUMBING		26			BOEING 304L SS	
COLD GAS SUPPLY SUPPORT		3			10 % OF SYS	
PROPELLANT SUPPLY - PROX-OPS (expend)			410			
N2 BOTTLE(S) - COLD GAS	4	248			BRUNSWICK 220064, (26.3 IN ID) KEVLAR O/W Ti	
VALVES	16	82			CONSOLIDATED CONTROLS	
FLIGHT DISCONNECT	1	1			PYRONETICS	
FILL / DRAIN DISCONNECT	4	4			PYRONETICS	
MANIFOLD/PLUMBING		8			BOEING 304L SS	
TANK VENT / RELIEF		14				
TANK SEPARATION	4	16			EXPLOSIVE BOLTS	
COLD GAS SUPPLY SUPPORT		37			10 % OF SYS	

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Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 3 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
POWER - ELECTRICAL				**2094**		**15**
POWER SUPPLY			1300		FUEL CELL SYSTEM - 6 KW NOM, 9 KW PEAK TOTAL	
FUEL CELLS	2	361			Reduced Shuttle Cells - 2 of 3 to supply sustained power	
BATTERIES	6	432			Contingency only - 48 kw-hr LI-SOCL2	
O2 TANKAGE (EPS & ECLSS)	2	90			20.0 in ID VACUUM -JACKETED TANK	
H2 TANKAGE	2	94			24.0 in ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	4	12				
REACTANT RELIEF, VENT PLUMBING	4	64				
REACTANT SUPPLY PLUMBING	4	20				
REACTANT SUPPLY VALVES, DISC	4	12				
COOLANT PLUMBING		45			INCL. 30 LB FLUIDS	
POWER SUPPLY SUPT/INSTL		170			15 % OF SYS	
POWER DIST EQUIP			169			
POWER DISTRIBUTION PANELS	3	99				
10VDC POWER SUPPLY	3	1				
EXTERIOR LIGHTS		15			ESTIMATE	
INTERIOR LIGHTS		20			ESTIMATE	
POWER DISTRIBUTION SUPT/INSTL		34			25 % OF SYS	
WIRING			625		ESTIMATE	
POWER DISTR. WIRE HARNESSES		350				
INSTRUMENTATION WIRING		100				
ELECTRICAL CONNECTORS		50			BULKHEAD FEEDTHRU PLATES	
HARNESS SUPT/INSTL		125			25 % OF SYS	
SURFACE CONTROLS				**121**		**15**
BODY FLAP ACTUATION			121		DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110				
ACTUATOR SUPT/INSTL		11			10 % OF SYS	

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Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 4 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
AVIONICS				**1637**		**15**
GUIDANCE, NAVIGATION AND CONTROL			229			
FAULT-TOLERANT NAVIGATOR	1	50				
GPS RECEIVER	2	12				
GPS ANTENNAS	2	10				
HORIZON SCANNER	2	12				
RADAR ALTIMETER	2	10				
BODY FLAP DRIVER	1	45				
RCS/ OMS VALVE DRIVER	2	90				
RENDEVOUS AND DOCK			133			
RENDEVOUS RADAR	1	30				
RADAR SIGNAL PROCESSOR	1	70				
ANTENNA	1	8				
ANTENNA MAST, DEPLOYMENT MECHS	1	25				
VEHICLE HEALTH MONITORING			75		SENSORS INCL IN INSTRUMENTATION COUNT	
MASS MEMORY	3	75				
COMMUNICATIONS AND TRACKING			238			
CENTRAL DATA FORMATTER	1	27				
TRANSPONDER	1	16				
POWER AMP	1	18				
DIPLEXER, RF SWITCH	1	3				
AUDIO	1	40				
UHF TRANSCEIVER	1	20				
ANTENNAS	3	24				
SEARCH AND RESCUE RADIO	1	40			ESTIMATED	
SIGNAL CABLING		50			ESTIMATED	
CONTROLS AND DISPLAYS			185			
RECONFIG DISPLAYS / CONTROL UNITS	5	50				
ELECTRONIC INTERFACES	3	75				
RECONFIG. PUSH-BUTTON PANEL	3	30				
RMS WORKSTATION	0	0			ESTIMATE FOR SERVICING MISSION	
HAND CONTROLLERS	2	30				
INSTRUMENTATION			83			
SENSOR INTERFACE UNIT (SIU)	60	30				
NETWORK INTERFACE UNIT (NIU)	2	3				
SENSORS, INSTRUMENTATION	700	50				
DATA HANDLING			463			
FAULT TOLERANT PROCESSOR	3	99				
MASS MEMORY	3	75				
DATA BUS COUPLERS	60	30			ESTIMATED	
MDM	7	259				
STRUCTURES/MECHS CONTROLS			82			
CHUTE, LANDING GEAR CONTROLLER	1	61				
LASER FIRING UNIT	2	20				
LASER INITIATORS	5	1				
AVIONICS SUPT/INSTL			149		10 % OF AVIONICS	

Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 5 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE) **NOTE: ALL MASS IN POUNDS**

ITEM	QTY	CREW ROTATION VALUE			REMARKS	WG%
ENVIRONMENTAL CONTROL				**1311**		**15**
CABIN AND PERSONNEL SYSTEM			350			
O2 TANKAGE - CRYO STORAGE	0	0			INCL IN FUEL CELL REACTANT STORAGE	
O2 TANKAGE - (GAS FOR REPRESS)	1	15			Kevlar / Inconel	
N2 TANKAGE - (GAS FOR REPRESS)	2	58			Kevlar / Titanium	
PRESS PLUMBING		12				
CABIN PRESS & COMPOSITION CNTRLS		52			VALVES, VENT RELIEF VALVES, ETC	
CO2 REMOVAL - 2-BED LIOH		11			LIOH CANISTER UNIT - 2 CANISTER UNIT	
LIOH CANISTER STORAGE - NOM		31				
LIOH CANISTER STORAGE - CONT		42				
TEMP AND HUMIDITY CONTROL		102			FANS/SEPARATORS, HEAT EXCHANGER, ETC	
TRACE CONTAMINANT CONTROL		7			CANISTER FOR IMPURITY REMOVAL	
DUCTING, MISC		20			FANS INCLUDED IN TEMPERATURE CONTROL	
EQUIPMENT COOLING			209			
EQUIPMENT COLD PLATES		120			S= 60 SF @ 2.0 PSF	
AVIONICS COOLING ASSY		28			INCL HX, FANS, DUCTING	
IMU HEAT EXCHANGER ASSY	1	31				
PLUMBING		20				
DUCTING, MISC		10			FANS INCLUDED IN TEMPERATURE CONTROL	
HEAT TRANSFER WATER LOOP			141			
HEAT EXCHANGER - POTABLE WATER	1	17			BASED ON SHUTTLE	
PRIMARY, SECONDARY WATER PUMPS		78				
PLUMBING		21				
COOLANT IN LOOP - WATER		25				
HEAT TRANSFER FREON LOOP			270			
HEAT EXCHANGER - WATER-FREON	1	50			BASED ON SHUTTLE	
HEAT EXCHANGER - GSE	1	50			BASED ON SHUTTLE	
HEAT EXCHANGER - FUEL CELL	1	50			BASED ON SHUTTLE	
FREON PUMP PACKAGE	2	90				
COOLANT IN LOOP - FREON		30				
HEAT REJECTION			222			
AMMONIA BOILER ASSEMBLY		45			INCL AMMONIA TANK, HEAT EXCHNGR, VENT, VALVES	
COOLANT TANKAGE - WATER		14				
FLASH EVAPORATOR - WATER		58			FROM SHUTTLE	
TOPPING DUCT ASSEMBLY		78				
HIGH LOAD DUCT ASSEMBLY		27				
RADIATOR PANELS			0		INCL ON PROPULSION MODULE	
ECLSS SUPT/INSTL			119		10 % OF ECLSS	

Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 6 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE) NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
OTHER - PERSONNELPROVISIONS				**978**		**15**
FOOD MANAGEMENT			117			
GALLEY		0			GALLEY UNIT, WITH WATER DISPENSER	
FOOD STORAGE UNITS		117				
WATER MANAGEMENT			52			
WATER STORAGE TANK	2	17			FOR POTABLE WATER STORAGE	
HANDWASH - WET WIPES		2				
WATER DISPENSER		23			WATER DISPENSER ONLY	
PLUMBING, VALVES, ETC		10				
WASTE MANAGEMENT			47			
WASTE WATER TANK	2	17				
COMMODE SYSTEM		15			installation scar only for crew rotation	
EMERGENCY WASTE COLLECTION		15			SHUTTLE TYPE	
FIRE DETECTION / SUPPRESSION			13			
SMOKE DETECTORS		7				
FIRE SUPPRESSION TANK		6			INCLUDES SUPPRESSANT	
FURNISHINGS AND EQUIPMENT			660			
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SLEEP STATIONS		0			NOT REQUIRED FOR TRANSFER	
INCIDENTAL EQUIPMENT	6	60			STORAGE FOR ASTRONAUT PERSONAL EFFECTS	
SUPPORT/INSTALLATION			89		10 % OF ECLSS	
OTHER - RECOVERY & AUXILIARY				**2081**		**15**
PARACHUTE SYSTEM			1405			
DROGUE CHUTES	1	234			12 + 0.00423 LB/LB INFLATION LOAD x 3g (MAX)	
BACKUP DROGUE	1	234				
MAIN CHUTE - HI-GLIDE	1	354			0.020 LB/LB INFLATION LOAD (MAX) @ 22 FPS	
BACKUP CHUTES - HI-GLIDE	1	354				
PARACHUTE CNTRL SPINDLE, MOTORS	2	100			ESTIMATE	
PARACHUTE SUPT/INSTL		128			10 % OF SYSTEM	
LANDING SYSTEM			486			
NOSE LANDING GEAR	1	86			0.005 LB/LB DESIGN LANDING WT (MAX)	
AFT LANDING GEAR	2	344			0.02 LB/LB DESIGN LANDING WT (MAX)	
FLOTATION COLLAR AIRBAGS	4	12				
LANDING GEAR SUPT/INSTL		44			10 % OF SYSTEM	
SEPARATION			190			
PARACHUTE COVERS SEPARATION	2	40			L=20 FT @ 2.0 LB/FT	
FWD FAIRING SEPARATION		60			L=20 FT @ 2.0 LB/FT	
LAUNCH VEHICLE SEP BOLTS	6	90				
CREW MOD DRY, EXCL GROWTH				**13851**		**15**
WEIGHT GROWTH MARGIN				**2078**	**15 % OF DRY WT**	

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Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 7 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			REMARKS	WG%
CREW MODULE DRY WEIGHT				15929		
NON- CARGO ITEMS				2266		
CREW, WITH EQUIPMENT			1800			
FLIGHT CREW / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects					90TH PERCENTILE + 107 lb ea.	
PROPELLANT RESIDUALS			83			
RCS RESIDUAL BI-PROP		34			RESIDUAL IN TANKS AND LINES	
RCS N2 PRESSURANT		14				
COLD GAS RESIDUALS		34				
PROPELLANT RESERVES			383			
RCS RESERVES - BIPROP		209			20% OF NOMINAL PROPELLANT	
RCS RESERVES - COLD GAS		174			20% OF NOMINAL PROPELLANT	
PAYLOAD / CARGO				0	**NO CARGO CAPABILITY**	
CREW MODULE INERT WEIGHT				18195		
NON- PROPELLANT				696		
IN-FLIGHT LOSSES			334		(CR- 264 KW-HR; SS- 840 KW-HR)	
FUEL CELL NOMINAL O2		238			0.71 LB/ KW -HR	
FUEL CELL NOMINAL H2		30			0.09 LB/ KW-HR	
FUEL CELL O2 RESERVES		48			20% NOMINAL	
FUEL CELL H2 RESERVES		6			20% NOMINAL	
FUEL CELL RESIDUAL REACTANT		13			ESTIMATE	
LIFE SUPPORT CONSUMABLES			362			
O2 - CRYO STORAGE		24			METABOLIC CONSUMPT. (2 LB/M-DAY) +20%+LEAKAGE	
O2 - GAS FOR REPRESSURIZATION		9			LEAK (0.38 LB/DAY)	
O2 - CABIN PRESSURIZATION		8				
N2 - GAS FOR REPRESS. LOSSES		40			LEAK (1.26 LB/DAY)	
N2 - CABIN PRESSURIZATION		38				
FOOD - NOMINAL		40			4 LB/M-DAY	
FOOD - CONTINGENCY		48			4 LB/M-DAY - 48 HR CONTINGENCY	
POTABLE WATER - NOMINAL		0			4 LB/M-DAY - SUPPLIED BY FUEL CELLS	
POTABLE WATER - CONTINGENCY		55			4 LB/M-DAY --48 HR CONTINGENCY	
EQUIP COOLING FLUIDS - ammonia		45			COOLANT FOR LAUNCH & REENTRY COOLING ONLY + 20 %	
EQUIP COOLING FLUIDS - water		55			WATER FOR HI-LOAD REJECTION + 20 %	
PROPELLANT - NOMINAL				450		
RCS NOM PROPELLANT - BIPROP			326			
RCS NOM PROPELLANT - COLD GAS			125			
OMS FLUIDS			0		INCL IN JETTISONABLE OMS POD	
GROSS WEIGHT, LESS OMS				19342		

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Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 8 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS		WG%
PROPULSION / RADIATOR MODULE				3551			
STRUCTURE			1312				
AFT ADAPTER INTERFACE RING	1	158			L=43 FT, A=3.0 IN2	ALUMINUM	
CREW MODULE INTERFACE RING	1	92			L=30.6 FT, A=2.5 IN2	ALUMINUM	
MINOR FRAMES	2	134			L=37.3 FT, A=1.5 IN2	ALUMINUM	
LONGERONS	6	257			L=11.9 FT, A=3.0 IN2	ALUMINUM	
INTERMEDIATE STRUTS / FTGS	18	248			L ave=7.1 FT, A=1.0 IN2 +1.0 LB FTGS	ALUMINUM	
RADIATOR PANEL LINKAGE & HINGES	2	40					
LAUNCH / CREW MOD UMBIL PLATES	2	60					
THRUST STRUCTURE	1	95			L=22 FT, A=3.0 IN2 +20%	ALUMINUM	
THRUST STR STABILIZING STRUTS	6	48					
THRUST RING / FTGS	1	25			D=40 IN, A=2.0 IN2	ALUMINUM	
ENG INTERFACE FTGS	3	9			ESTIMATE		
TANK SUPPORT STRUTS	8	66			L= 72 IN, A=1.0 IN2 + 1 LB FTGS EA	ALUMINUM	
TANK SWAY STRUTS	16	72			L=40 IN, A=1.0 IN2 + 1 LB FTG EA	ALUMINUM	
PRESS TANK SUPT FLANGES	8	8			ESTIMATE	ALUMINUM	
THERMAL PROTECTION			71		S= 1034 SF, @ 0.0685 PSF	FOSR	
PROPULSION - OMS			803		LO2/RP SYSTEM; EXTERNAL PRESS		
ENGINES	3	150					
ENGINE MOUNT	3	15					
LO2 SYSTEM - TANK	2	74			41.0 in ID TANK, WITH INSULATION	ALUMINUM	
LO2 SYSTEM - VALVES	6	24					
LO2 SYSTEM - MANIFOLD	1	28			4 FT @ 5.8 LB/FT + 5 FT @ 1 LB/FT	ALUMINUM	
LO2 SYSTEM - LES VALVES	1	20					
LO2 SYSTEM - LES DISCONNECT	1	12					
LO2 SYSTEM - FILL, DRAIN, VENT	1	24					
LO2 SYSTEM - SUPPORT, INSTL		27			15 % OF OMS		
RP SYSTEM - TANK	2	92			35.0 in ID TANK, WITH INSULATION	ALUMINUM	
RP SYSTEM - VALVES	6	24					
RP SYSTEM - MANIFOLD	1	19			4 FT @ 3.5 LB/FT + 5.0 FT @ 1 LB/FT	ALUMINUM	
RP SYSTEM - LES VALVES	1	20					
RP SYSTEM - LES DISCONNECT	1	12					
RP SYSTEM - FILL, DRAIN, VENT	1	24					
RP SYSTEM - SUPPORT, INSTL		29			15 % OF OMS		
GN2 BOTTLES - OMS	2	128			SCI 1270365 , 4500 PSI		
GAS VALVES	4	18			MOOG		
REGULATORS	2	9			FAIRCHILD		
FILL & DRAIN DISCONNECTS	2	2			PYRONETICS		
MANIFOLD/PLUMBING		10			BOEING 304L SS		
BOTTLE VENT / RELIEF		17			FAIRCHILD		
PRESS SYSTEM SUPPORT		25			15 % OF OMS		
POWER DISTRIBUTION			188				
WIRING, INCL GROUND UMBILICALS		150					
EQUIPMENT SUPPORT/INSTL		38			25 % OF WIRING	ALUMINUM	
ECLSS RADIATOR PANELS			564				
COOLANT IN PANELS - FREON		30					
FIXED PANELS	2	304			A=134 sf ea @ 1.14 psf	ALUMINUM	
DEPLOYED PANELS	2	230			A=67 sf ea (67 sf ea side) @ 1.72 psf	ALUMINUM	
OTHER - AUXILIARY SYSTEMS			150				
LAUNCH VEHICLE SEPARATION	6	90			EXPLOSIVE BOLT SEPARATION		
CREW MODULE SEPARATION	6	60			EXPLOSIVE BOLT SEPARATION		
WEIGHT GROWTH MARGIN			463		15 % OF HARDWARE		

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Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 9 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
OMS PROPELLANTS				2798		
OMS RESIDUALS			204			
RESIDUALS - IN TANKS		73			0.3 FT3 PER TANK	
RESIDUALS - IN LINES, ENGINES		66			4 FT EA, 5.0 IN DIA.	
PRESSURANTS		65			0.0251 LB/LB PROPELLANT NITROGEN	
OMS RESERVES			236			
RESERVE PROPELLANT		236			10% OF NOMINAL	
OMS NOMINAL PROPELLANT			2358		DELTA V AS SHOWN	
ON-ORBIT GROSS WEIGHT				25691		
LAUNCH VEHICLE ADAPTER				1956		
STRUCTURE			1363		S= 545 SF @ 2.5 PSF ALUM SKIN/STR	
PROTECTION - THERMAL			0			
POWER - WIRE HARNESS			188		L= 8 FT, INCL CONNECTORS, ETC	
OTHER - CREW MOD SEPARATION SYS	6		150		SEP BOLTS	
WEIGHT GROWTH MARGIN			255		15 % OF HARDWARE	
FORWARD FAIRING				2700		
STRUCTURE			1747			
FAIRING NOSE CAP		45			S= 15 SF @ 3.0 PSF	
FAIRING - CONIC SECTION		1148			S= 574 SF @ 2.0 PSF AL SKIN/STRNGR	
FAIRING - CYLINDRICAL SECTION		444			S= 222 SF @ 2.0 PSF AL SKIN/STRNGR	
FAIRING - FLAT SECTION COVER		110			S= 55 SF @ 2.0 PSF AL SKIN/STRNGR	
PROTECTION - THERMAL			239		S=796 SF @ 0.3 PSF SPRAY-ON FOAM	
OTHER - AUXILIARY SYS			362			
SEPARATION JOINTS		212			L= 106 FT @ 2.0 LB/FT SUPER-ZIP	
SEPARATION SPRINGS/FTGS		150			ESTIMATE	
WEIGHT GROWTH MARGIN			352		15 % OF HARDWARE	
BALLAST				0		
FWD NOSE BALLAST			0			

Table 21.3-6 Detailed Mass Properties for Configuration II (6 Persons) (Page 10 of 10)

GROUP WEIGHT STATEMENT
FLATTENED BICONIC PLS - Concept #2 (6 PERSONNEL SIZE) NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS		WG%
EXPENDABLE LAUNCH ESCAPE SYSTEM				3264			
STRUCTURE			260				
ENGINE THRUST STRUCTURE		173			L=30 FT, A=4.0 IN2 + 20%	ALUMINUM	
STABILIZING STRUTS, FTGS, ETC		87			ESTIMATE		
PROPULSION - LIQUID LES			2220				
TURBOPUMP ASSEMBLY	1	1140					
ENGINE	1	250					
ENGINE / TURBOPUMP MOUNT	1	20					
GAS GENERATOR	1	200					
GAS GENERATOR TANKAGE (WET)	1	160					
LO2 SYSTEM - DISCONNECT	1	12			DIA=5.0 IN		
LO2 SYSTEM - VALVE	1	20			DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	114			DIA = 5.0 IN, L=20 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			DIA=5.0 IN		
RP SYSTEM - VALVE	1	20			DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	70			DIA = 5.0 IN, L=20 FT @ 3.5 LB/FT	ALUMINUM	
EQUIPMENT SUPPORT/INSTL		202				10 % OF EQUIPMENT	
POWER - WIRE HARNESS			40		SCALED FROM APOLLO		
OTHER - SEPARATION BOLTS	4		32				
WEIGHT GROWTH MARGIN			383			15 % OF HARDWARE	
OMS RESIDUALS			329		20 FT EA, 5.0 IN DIA.		
TOTAL LAUNCH WEIGHT				33611			

SEQUENCED MASS DATA

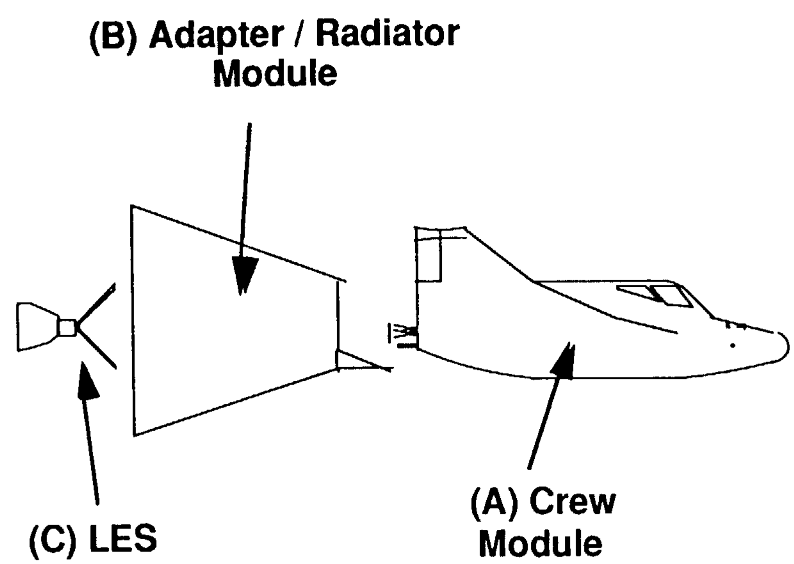
ITEM	QTY	VALUE	REMARKS	WG%
TOTAL WEIGHT		33611		
SEPARATE FROM LAUNCH VEH ADAPTER		-1956		
ON-PAD ABORT WEIGHT		31655		
ON-ORBIT WEIGHT		25691		
DELETE CONSUMABLES TO REENTRY		-62		
DELETE POWER FLUIDS TO REENTRY		-258		
DELETE NOMINAL RCS ON-ORBIT PROP		-243		
DELETE ALL PROX OPS COLD GAS		-333		
DELETE ALL OMS ON-ORBIT PROP		-2798		
SEPARATE PROX-OPS TANKS		-472		
SEPARATE OMS POD		-3551		
BEGIN REENTRY WEIGHT		17974		
DELETE CONSUMABLES		-19		
DELETE REENTRY POWER FLUIDS		-10		
DELETE NOMINAL RCS REENTRY PROP		-83		
DEPLOY PARACHUTES		-677		
LANDING WEIGHT		17185		

Table 21.3-7 Summary Weight Statement - Configuration III

Crew / Passengers: 2 / 8 — Mission Duration : 72 Hour

Functional System	A	B	C	D
1. Structure	7311	989	68	
2. Protection	3201	71		
3. Propulsion	1559		2211	
4. Power - Electrical	2205	188		
5. Control	242			
6. Avionics	1686			
7. Environment	1471	795		
8. Other - Personnel Provisions	1486			
Other - Landing, Aux Systems	2275	150		
9. Weight Growth Margin	3215	329	342	
Dry Mass	**24651**	**2522**	**2621**	
10. Non- Cargo (See Note 1)	4266	0		
11. Cargo	0	0		
Inert Mass	**28917**	**2522**	**2621**	
12. Non- Propellant Consumables	855			
13. Propellant - Nominal	3983	0		
Gross Mass	**33755**	**2522**	**2621**	
	36277		2621	
Total Mass	**38898**			

Configuration: Lifting Body



All Mass in Pounds

Notes:
A Crew Module
B Adapter / Radiator Module
C Launch Escape System (LES)
D Fwd Fairing

1 Includes Flight Crew + Equipment (600 Lb), Passengers +Equip (2400 Lb), And Propellant Reserves / Residuals

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Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 1 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS) **NOTE: ALL MASS IN POUNDS**

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PERSONNEL			10					
CREW		2						
PASSENGERS		8						
MISSION DURATION (DAYS)			3.0					
ECLSS								
CLOSURE LEVEL			OPEN					
PRESSURIZED VOLUME -CABIN (FT3)			1022.0					
PRESSURIZED VOLUME -AIRLOCK (FT3)			0.0					
PRESS/REPRESS EVENTS			2.0					
CABIN LEAKAGE (%VOLUME/DAY)			2.0					
PROPULSION		Delta V	Isp,sec					
RCS - H2O2/RP		146	310					
COLD GAS - N2		10	60					
OMS - LO2/RP		989	315					
LES - Expend Liquid Pusher		606	310					
ON-PAD ABORT WEIGHT			38899					
ON-ORBIT WEIGHT			36278					
LANDING WEIGHT			29423					
DESIGN LANDING WEIGHT			30000					
STRUCTURE - TAIL GROUP				**628**	**199**			**15**
TIP FIN BASIC STRUCTURE			554					
LEADING EDGE	2	50			225	S= 7.2 SF EA. @ 3.5 PSF	TITANIUM	
TORQUE BOX	2	490			202	S= 70.0 SF EA. @ 3.5 PSF	ALUMINUM	
TRAILING EDGE - FIXED	2	14			180	S= 2.0 SF EA. @ 3.5 PSF	TITANIUM	
CONTROL SURFACES			74					
RUDDER	2	67			168	S= 8.4 SF EA. @ 4.0 PSF	TITANIUM	
RUDDER SUPPORT MECHANISMS	2	5			180	7% OF RUDDER MASS		
RUDDER ACTUATOR/FITTINGS	2	2			180	3% OF RUDDER MASS		

Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 2 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS) **NOTE: ALL MASS IN POUNDS**

ITEM	QTY	CREW ROTATION VALUE			XCG	REMARKS		WG%
STRUCTURE - BODY GROUP				**6751**	**176**			**15**
FWD FUSELAGE BASIC STRUCTURE			858			(X.260- X.360)	ALUM SKIN / STR	
FWD BULKHEAD - STA. 360	1	33			360	S= 16.5 SF @ 2.0 PSF		
MAJOR FRAME - STA. 300	1	103			300	L = 28.3 ft, A=3.0 in2		
AFT BULKHEAD - STA. 270	1	82			270	S= 41.0 SF @ 2.0 PSF		
MINOR FRAMES	2	95			310	L, ave = 26.0 ft, A=1.5 in2		
JOINTS, SPLICES, FASTENERS		47			300	15% OF FRAMES, BULKHEADS		
COVER PANELS, UPPER (LESS ACCESS)		137			304	S=80.7 SF @ 1.7 PSF		
COVER PANELS, LWR (LESS LG DOOR)		176			304	S=103.5 SF @ 1.7 PSF		
LONGERONS - FWD BODY	3	67			310	L= 9.2 FT ea, A=2.0 IN2		
NOSE WHEEL WELL & FRAMES	1	60			323	S=20 SF @ 3.0 PSF		
NOSE WHEEL SUPT STRUTS	4	58			323	L= 6.0 FT, A=2.0 IN2		
MID FUSELAGE BASIC STRUCTURE			1448			(X.80- X.260)	ALUM SKIN / STR	
BULKHEAD - STA. 230	1	106			230	S=53 SF @ 2.0 PSF		
BULKHEAD - STA. 160	1	106			160	S=53 SF @ 2.0 PSF		
MINOR FRAMES	3	118			170	L = 32.4 ft, A=1.0 in2		
JOINTS, SPLICES, FASTENERS		50			170	15% OF FRAMES, BULKHEADS		
COVER PANELS, UPPER		337			170	S=198 SF @ 1.7 PSF		
COVER PANELS, LOWER		469			170	S=276 SF @ 1.7 PSF		
LONGERONS - MID BODY	3	109			170	L= 15.0 FT ea, A=2.0 IN2		
MAIN WHEEL WELL & FRAMES	2	120			195	S=20 SF @ 3.0 PSF		
FTGS, CABIN ATTACHMENT	22	33			170			
AFT FUSELAGE BASIC STRUCTURE			785			(X.0- X.80)	ALUM SKIN / STR	
BULKHEAD - STA 80	1	198			80	S= 38 SF @ 5.2 PSF		
AFT BULKHEAD - STA. 0	1	94			0	S= 55 SF @ 1.7 PSF		
MINOR FRAMES - AFT BODY	1	51			40	L, ave=28.0 ft, A=1.5 in2		
JOINTS, SPLICES, FASTENERS		37			40	15% OF FRAMES, BULKHEADS		
COVER PANELS, UPPER		157			40	S=92 SF @ 1.7 PSF		
COVER PANELS, LOWER		199			40	S=117 SF @ 1.7 PSF		
LONGERONS - AFT BODY	3	49			40	L=6.7 FT, A=2.0 IN2		
THRUST STRUCTURE - OMS (FIXED)			272					
THRUST STRUTS	4	78			40	L=6.7 FT, A=2.0 IN2 +20%	ALUMINUM	
THRUST STR STABILIZING STRUTS	TBD	39			40			
ENG INTERFACE FTGS	3	9			0	ESTIMATE		
TANK SUPPORT STRUTS	8	66			35	L= 72 IN, A=1.0 IN2 + 1 LB FTGS EA	ALUMINUM	
TANK SWAY STRUTS	16	72			35	L=40 IN, A=1.0 IN2 + 1 LB FTG EA	ALUMINUM	
PRESS TANK SUPT FLANGES	8	8			40	ESTIMATE	ALUMINUM	
THRUST STRUCT. - LAUNCH ESCAPE (JETT)			68					
ENGINE THRUST STRUTS	3	29			-20	L=5 FT, A=4.0 IN2 + 20%	ALUMINUM	
STABILIZING STRUTS, FTGS, ETC	TBD	15			-20	ESTIMATE		
THRUST STRUCT SEPARATION BOLTS	3	24			0			
FWD FUSELAGE SECONDARY STRUCTURE			279					
WINDOW, THERMAL	4	29			270	S,ave=0.8 SF EA @ 9.0 PSF		
WINDOW, RETAINER	4	10			270			
DOCKING HATCH COVER	0	0			0			
DOCKING COVER HINGES, MECHANISM	0	0			0			
DOORS, FRAMES - NOSE LANDING GEA	1	57			321	S= 11.0 SF @ 5.2 PSF	ALUMINUM	
NOSE LANDING GEAR SUPPORT	1	103			321			
ACCESS PANELS	2	48			321	S= 8 SF EACH @3.0 PSF	ALUMINUM	
EQUIPMENT SUPPORT RACKS	2	32			321	S= 8 SF EA.@ 2.0 PSF	ALUMINUM	

Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 3 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS) — **NOTE: ALL MASS IN POUNDS**

ITEM	CREW ROTATION QTY	VALUE		XCG	REMARKS		WG%
MID FUSELAGE SECONDARY STRUCT			354				
DOORS, FRAMES - MAIN LANDING GEAR	2	104		195	S= 10.0 SF EA.@ 5.2 PSF	ALUMINUM	
MAIN LANDING GEAR SUPPORT	2	206		200			
RMS GRAPPLE FITTING	2	44		170			
AFT FUSELAGE SECONDARY STRUCT			208				
SERVICE MODULE UMBILICAL PLATE	1	20		0			
LAUNCH/PROP MODULE UMBIL PLATE	1	20		0			
BODY FLAP	1	108		-12	S= 12 SF @ 9.0 PSF	RCC/ INSTL	
BODY FLAP CLOSEOUT/HINGE SUPT	1	60		0	S=6.7 SF @ 9.0 PSF		
CREW MODULE BASIC STRUCTURE			1488			ALUMINUM SKIN / STRINGER	
BULKHEAD, FWD	1	54		276	S=72 SF @ 0.75 PSF	ALUMINUM	
BULKHEAD, AFT	1	54		64	S= 72 SF @ 0.75 PSF	ALUMINUM	
MINOR FRAMES, CABIN	7	320		170	L, ave= 25.2 FT , A= 1.5 IN2	ALUMINUM	
COVER PANELS, UPPER		440		170	S=259 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, LOWER		287		170	S= 169 SF @ 1.7 PSF	ALUMINUM	
FLOORING, EQUIP SUPT		300		170	S= 150 SF @ 2.0 PSF	ALUMINUM	
FTGS, CABIN ATTACHMENT	22	33		170			
CREW MODULE SECONDARY STRUCTURE			992			ALUMINUM SKIN / STRINGER	
INTERNAL EQUIPMENT BAY	1	84		115	S= 56 SF @ 1.5 PSF		
EQUIPMENT SUPPORT RACKS	2	150		85	S=100 SF @ 1.5 PSF		
WINDOWS	6	130		270	S= 0.8 SF EA @ 27 PSF		
WINDOWS, RETAINER	6	65		270			
DOCKING ADAPTER MECHANISM	1	340		285			
AIRLOCK INTERFACE RING	0	0		0	L= 13.0 FT, A= 2.5 IN2 + 20%	ALUMINUM	
TOP HATCH, STRUCTURE	1	58		100	36-IN DIA		
TOP HATCH, MECHANISM	1	32		100			
DOCKING HATCH, STRUCTURE	1	72		285	40-IN DIA, SHUTTLE-TYPE (8.7 sf)		
DOCKING HATCH, WINDOW & RETAINER	1	20		285			
DOCKING HATCH, MECHANISM	1	41		285			

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Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 4 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS) — **NOTE: ALL MASS IN POUNDS**

ITEM	QTY	CREW ROTATION VALUE			XCG	REMARKS		WG%
PROTECTION				**3201**	**199**			**15**
EXTERNAL TPS - WINGLETS			618					
TIP FIN LEADING EDGE - HRSI		84			202	S= 14.4 SF EA. @ 2.94 PSF	FRCI-12 w/SiC cover	
TIP FIN SURFACE - LRSI		406			202	S= 144 SF EA. @ 1.41 PSF	FRCI-12	
RUDDER SURFACE - LRSI		47			168	S= 16.8 SF EA. @ 1.41 PSF	FRCI-12	
THERMAL BARRIERS / SEALS		81			180	15% OF TPS WEIGHTS		
EXTERNAL TPS - BODY			2170					
NOSE CAP, PANELS - RCC		75			370	S= 15.0 SF @ 5 PSF	RCC/INSTL	
NOSE CAP, INSTL HDWARE		45			370	60% OF RCC WEIGHT		
NOSE CAP, BULK INSULATION		102			360	S=17 SF @ 6.0 PSF		
BODY TPS - HRSI (FWD)		304			304	S=103.5 SF @ 2.94 PSF	FRCI-12 w/SiC cover	
BODY TPS - HRSI (MID/AFT)		1155			130	S=393 SF @ 2.94 PSF	FRCI-12 w/SiC cover	
MAIN LANDING GEAR DOORS - HRSI	2	70			195	S=10 SF EA.@ 3.5 PSF, incl closeouts	FRCI-12 w/SiC cover	
NOSE GEAR DOOR TPS - HRSI	1	39			323	S=11 SF @ 3.5 PSF, incl closeouts	FRCI-12 w/SiC cover	
BODY TPS - LRSI (FWD)		114			304	S=81 SF @ 1.41 PSF	FRCI-12	
BODY TPS - LRSI (MID)		99			240	S=70 SF @ 1.41 PSF	FRCI-12	
BODY TPS - FRSI		115			130	S=220 SF @ .522 PSF	Rigid TABI	
ACCESS PANEL TPS - LRSI		23			321	S= 16 SF @ 1.41 PSF	FRCI-12	
AFT BULKHEAD TPS - FRSI		29			0	S=55 SF @ 0.522 PSF	Rigid TABI	
INTERNAL INSULATION / TCS			332					
BULK INSULATION - FWD BODY		77			320	S= 220 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSULATION - FWD BODY		15			320	S= 220 SF @ 0.07 PSF	MLI	
BULK INSULATION - CREW MODULE		200			170	S= 570 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSUL. - CREW MODULE		40			170	S= 570 SF @ 0.07 PSF	MLI	
PURGE AND VENT SYSTEM			63			SCALED FROM SHUTTLE		
DUCTING		30			170			
VALVES		20			170			
SUPPORT, INSTALLATION		13			170			
WINDOW / HATCH CONDITIONING			19			SCALED FROM SHUTTLE		
PLUMBING		7			270			
DESSICANT, VALVES, DISCONNECTS		8			270			
SUPPORT, INSTALLATION		4			270			
RECOVERY & AUXILIARY SYSTEMS				**2275**	**68**			**15**
DROGUE CHUTE SYSTEM			1556					
DROGUE CHUTES	1	380			15	FOR ABORT CONDITION OR BRAKED LANDING		
BACKUP DROGUE	1	380			15			
ABORT MAIN CHUTES	3	720			15			
PARACHUTE SUPT/INSTL		76			15	10 % OF SYSTEM		
LANDING SYSTEM			593					
NOSE LANDING GEAR	1	108			323	0.005 LB/LB DESIGN LANDING WT (MAX)		
MAIN LANDING GEAR	2	431			195	0.02 LB/LB DESIGN LANDING WT (MAX)		
LANDING GEAR SUPT/INSTL		54			238	10 % OF SYSTEM		
SEPARATION			126					
LAUNCH ESCAPE MOTOR SEPARATION	3	36			0			
LAUNCH VEHICLE SEP BOLTS	6	90			0			

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Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 5 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
PROPULSION - REACTION CONTROL				**996**	**151**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**	**15**
THRUSTER MODULES - FORWARD			116		352		
THRUSTERS - RCS	10	83					
THRUSTERS - COLD GAS	6	22				MOOG 5264 - 30 LBF N2 THRUSTERS	
THRUSTER MODULE SUPPORT	4	11				10 % OF SYS	
THRUSTER MODULES - AFT			97		40		
THRUSTERS - RCS	8	66					
THRUSTERS - COLD GAS	6	22				MOOG 5264 - 30 LBF N2 THRUSTERS	
THRUSTER MODULE SUPPORT	4	9				10 % OF SYS	
PRESSURIZATION SYSTEM			23		196		
GN2 BOTTLE(S) - RCS	0	0				INCL IN COLD GAS SYSTEM	
REGULATORS	0	0				FAIRCHILD	
FILL & DRAIN DISCONNECTS	1	1				PYRONETICS	
MANIFOLD/PLUMBING		10				BOEING	
TANK VENT / RELIEF		9					
PRESS SYS SUPPORT		3				15 % OF SYS	
PROPELLANT SUPPLY - RCS			200		185		
TANKAGE - H2O2	2	60				31.0-IN DIAMETER SPHERICAL NEW	
TANKAGE - RP	2	22				16.5-IN DIAMETER SPHERICAL NEW	
VALVES	9	35				CONSOLIDATED CONTROLS	
MANIFOLD/PLUMBING	1	40				BOEING 304L SS	
TANK FILL, VENT & DRAIN	2	25					
PROPELLANT SUPPLY SUPPORT		18				10 % OF SYS	
PROPELLANT SUPPLY - PROX-OPS (fixed)			560		115		
N2 BOTTLE(S) - OMS, RCS, COLD GAS	4	350				15-IN ID X 74-IN LONG KEVLAR O/W Ti	
VALVES	16	82				CONSOLIDATED CONTROLS	
FLIGHT DISCONNECT	1	1				PYRONETICS	
FILL / DRAIN DISCONNECT	4	4				PYRONETICS	
MANIFOLD/PLUMBING		42				BOEING 304L SS	
TANK VENT / RELIEF		14					
TANK SEPARATION	4	16				EXPLOSIVE BOLTS	
COLD GAS SUPPLY SUPPORT		51				10 % OF SYS	

Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 6 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			XCG	REMARKS		WG%
PROPULSION - ORBIT MANEUVER				**563**	**31**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
THRUSTER MODULES			165					
ENGINES	3	150			-10			
ENGINE MOUNT	3	15			-2			
PRESSURIZATION SYSTEM			62					
GN2 BOTTLES - OMS	0	0			0	INCL IN COLD GAS SYSTEM		
GAS VALVES	4	18			75	MOOG		
REGULATORS	2	9			75	FAIRCHILD		
FILL & DRAIN DISCONNECTS	2	2			75	PYRONETICS		
MANIFOLD/PLUMBING		10			50	BOEING 304L SS		
BOTTLE VENT / RELIEF		17			75	FAIRCHILD		
PRESS SYSTEM SUPPORT		6			75	15 % OF OMS		
PROPELLANT SUPPLY - OMS			336					
LO2 SYSTEM - TANK	2	102			50	44.0 in ID TANK, WITH INSULATION	ALUMINUM	
LO2 SYSTEM - VALVES	4	16			50			
LO2 SYSTEM - MANIFOLD	1	20			50	8 FT @ 2.5 LB/FT	ALUMINUM	
LO2 SYSTEM - FILL, DRAIN, VENT	1	24			50			
LO2 SYSTEM - SUPPORT, INSTL		24			50	15 % OF OMS		
RP SYSTEM - TANK	2	70			35	35.0 in ID TANK, WITH INSULATION	ALUMINUM	
RP SYSTEM - VALVES	4	16			35			
RP SYSTEM - MANIFOLD	1	20			35	8 FT @ 2.5 LB/FT	ALUMINUM	
RP SYSTEM - FILL, DRAIN, VENT	1	24			35			
RP SYSTEM - SUPPORT, INSTL		20			35	15 % OF OMS		
PROPULS - LAUNCH ESCAPE SYSTEM				**2211**	**-33**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
LAUNCH ESC MOTOR / TURBOPUMP (JETT)			1410					
TURBOPUMP ASSEMBLY	2	1140			-40	ESTIMATE		
ENGINE	1	250			-60	ESTIMATE		
ENGINE / TURBOPUMP MOUNT	1	20			-45			
TURBOPUMP GAS GENERATOR (JETT)			360					
GAS GENERATOR	1	200			-40	ESTIMATE		
GAS GENERATOR TANKAGE (WET)	1	160			-40	ESTIMATE		
PROPELLANT SUPPLY (JETT)			71					
LO2 SYSTEM - DISCONNECT	1	12			0	DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	29			-20	DIA = 5.0 IN, L=5 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			0	DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	18			-20	DIA = 5.0 IN, L=5 FT @ 3.5 LB/FT	ALUMINUM	
PROPELLANT SUPPLY (FIXED)			169					
LO2 SYSTEM - DISCONNECT	1	12			2	DIA=5.0 IN		
LO2 SYSTEM - VALVE	2	40			10	DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	40			25	DIA = 5.0 IN, L=7 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			2	DIA=5.0 IN		
RP SYSTEM - VALVE	2	40			10	DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	25			20	DIA = 5.0 IN, L=7 FT @ 3.5 LB/FT	ALUMINUM	
EQUIPMENT SUPPORT/INSTL			201		10	10 % OF EQUIPMENT		

Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 7 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
POWER - ELECTRICAL				**2205**	**216**		**15**
POWER SUPPLY			1348			FUEL CELL SYSTEM - 6 KW NOM, 9 KW PEAK TOTAL	
FUEL CELLS	2	361			260	Reduced Shuttle Cells - 2 of 3 to supply sustained power	
BATTERIES	6	432			315	Contingency only - 48 kw-hr LI-SOCL2	
O2 TANKAGE (EPS & ECLSS)	2	110			185	21.0 in ID VACUUM -JACKETED TANK	
H2 TANKAGE	2	116			185	26.0 in ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	4	12			185		
REACTANT RELIEF, VENT PLUMBING	4	64			185		
REACTANT SUPPLY PLUMBING	4	20			220		
REACTANT SUPPLY VALVES, DISC	4	12			220		
COOLANT PLUMBING		45			260	INCL. 30 LB FLUIDS	
WASTE WATER TANK		0				INCL IN WATER MANAGEMENT	
POWER SUPPLY SUPT/INSTL		176			220	15 % OF SYS	
POWER DIST EQUIP			169				
POWER DISTRIBUTION PANELS	3	99			85		
10VDC POWER SUPPLY	3	1			85		
EXTERIOR LIGHTS		15			170	ESTIMATE	
INTERIOR LIGHTS		20			170	ESTIMATE	
POWER DISTRIBUTION SUPT/INSTL		34			450	25 % OF SYS	
WIRING			688			ESTIMATE	
POWER DISTR. WIRE HARNESSES		400			173		
INSTRUMENTATION WIRING		100			85		
ELECTRICAL CONNECTORS		50			85	BULKHEAD FEEDTHRU PLATES	
HARNESS SUPT/INSTL		138			150	25 % OF SYS	
SURFACE CONTROLS				**242**	**11**		**15**
RUDDER ACTUATION			121			DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110			22		
ACTUATOR SUPT/INSTL		11			22	10 % OF SYS	
BODY FLAP ACTUATION			121			DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110			0		
ACTUATOR SUPT/INSTL		11			0	10 % OF SYS	

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Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 8 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
AVIONICS				1686	121		15
GUIDANCE, NAVIGATION AND CONTROL			274		85		
FAULT-TOLERANT NAVIGATOR	1	50					
GPS RECEIVER	2	12					
GPS ANTENNAS	2	10					
HORIZON SCANNER	2	12					
RADAR ALTIMETER	2	10					
RUDDER DRIVER	1	45					
BODY FLAP DRIVER	1	45					
RCS/ OMS VALVE DRIVER	2	90					
RENDEVOUS AND DOCK			133		260		
RENDEVOUS RADAR	1	30					
RADAR SIGNAL PROCESSOR	1	70					
ANTENNA	1	8					
ANTENNA MAST, DEPLOYMENT MECHS	1	25					
VEHICLE HEALTH MONITORING			75			SENSORS INCL IN INSTRUMENTATION COUNT	
MASS MEMORY	3	75			85		
COMMUNICATIONS AND TRACKING			238		85		
CENTRAL DATA FORMATTER	1	27					
TRANSPONDER	1	16					
POWER AMP	1	18					
DIPLEXER, RF SWITCH	1	3					
AUDIO	1	40					
UHF TRANSCEIVER	1	20					
ANTENNAS	3	24					
SEARCH AND RESCUE RADIO	1	40				ESTIMATED	
SIGNAL CABLING		50				ESTIMATED	
CONTROLS AND DISPLAYS			185		270		
RECONFIG DISPLAYS / CONTROL UNITS	5	50					
ELECTRONIC INTERFACES	3	75					
RECONFIG. PUSH-BUTTON PANEL	3	30					
RMS WORKSTATION	0	0				ESTIMATE FOR SERVICING MISSION	
HAND CONTROLLERS	2	30					
INSTRUMENTATION			83				
SENSOR INTERFACE UNIT (SIU)	60	30			170		
NETWORK INTERFACE UNIT (NIU)	2	3			85		
SENSORS, INSTRUMENTATION	700	50			170		
DATA HANDLING			463		85		
FAULT TOLERANT PROCESSOR	3	99					
MASS MEMORY	3	75					
DATA BUS COUPLERS	60	30				ESTIMATED	
MDM	7	259					
STRUCTURES/MECHS CONTROLS			82				
CHUTE, LANDING GEAR CONTROLLER	1	61			40		
LASER FIRING UNIT	2	20			40		
LASER INITIATORS	5	1			40		
AVIONICS SUPT/INSTL			153		85	10 % OF AVIONICS	

Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 9 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			XCG	REMARKS	WG%
ENVIRONMENTAL CONTROL				**1471**	**76**		**15**
CABIN AND PERSONNEL SYSTEM			475				
O2 TANKAGE - CRYO STORAGE	0	0			0	INCL IN FUEL CELL REACTANT STORAGE	
O2 TANKAGE - (GAS FOR REPRESS)	1	25			40	Kevlar / Inconel	
N2 TANKAGE - (GAS FOR REPRESS)	2	96			115	Kevlar / Titanium	
PRESS PLUMBING		12			115		
CABIN PRESS & COMPOSITION CNTRLS		65			85	VALVES, VENT RELIEF VALVES, ETC	
CO2 REMOVAL - 2-BED LiOH		11			85	LiOH CANISTER UNIT - 2 CANISTER UNIT	
LiOH CANISTER STORAGE - NOMINAL		43			85	(7.0 LB/2-PERSON-DAY)	
LiOH CANISTER STORAGE - CONTING.		70			85	48-HR @(7.0 LB/2-PERSON-DAY)	
TEMP AND HUMIDITY CONTROL		127			85	FANS/SEPARATORS, HEAT EXCHANGER, ETC	
TRACE CONTAMINANT CONTROL		7			85	CANISTER FOR IMPURITY REMOVAL	
DUCTING, MISC		20			170	FANS INCLUDED IN TEMPERATURE CONTROL	
EQUIPMENT COOLING			209		85		
EQUIPMENT COLD PLATES		120				S= 60 SF @ 2.0 PSF	
AVIONICS COOLING ASSY		28				INCL HX, FANS, DUCTING	
IMU HEAT EXCHANGER ASSY	1	31					
PLUMBING		20					
DUCTING, MISC		10				FANS INCLUDED IN TEMPERATURE CONTROL	
HEAT TRANSFER WATER LOOP			161		120		
HEAT EXCHANGER - POTABLE WATER	1	17				BASED ON SHUTTLE	
PRIMARY, SECONDARY WATER PUMPS		78					
PLUMBING		30					
COOLANT IN LOOP - WATER		36					
HEAT TRANSFER FREON LOOP			270				
HEAT EXCHANGER - WATER-FREON	1	50			40	BASED ON SHUTTLE	
HEAT EXCHANGER - GSE	1	50			40	BASED ON SHUTTLE	
HEAT EXCHANGER - FUEL CELL	1	50			40	BASED ON SHUTTLE	
FREON PUMP PACKAGE	2	90			40		
COOLANT IN LOOP - FREON		30			40		
HEAT REJECTION			222		30		
AMMONIA BOILER ASSEMBLY		45				INCL AMMONIA TANK, HEAT EXCHNGR, VENT, VALVES	
COOLANT TANKAGE - WATER		14					
FLASH EVAPORATOR - WATER		58				FROM SHUTTLE	
TOPPING DUCT ASSEMBLY		78					
HIGH LOAD DUCT ASSEMBLY		27					
RADIATOR PANELS			0			INCL ON AFT ADAPTER	
ECLSS SUPT/INSTL			134		100	10 % OF ECLSS	

Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 10 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)
NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
PERSONNELPROVISIONS				1486	178		15
FOOD MANAGEMENT			117				
GALLEY		0			85	GALLEY UNIT, WITH WATER DISPENSER	
FOOD STORAGE UNITS		117			85		
WATER MANAGEMENT			63		120		
WATER STORAGE TANK	2	28				FOR POTABLE WATER STORAGE	
HANDWASH - WET WIPES		2					
WATER DISPENSER		23				WATER DISPENSER ONLY	
PLUMBING, VALVES, ETC		10					
WASTE MANAGEMENT			58		140		
WASTE WATER TANK	2	28					
COMMODE SYSTEM		15				installation scar only for crew rotation	
EMERGENCY WASTE COLLECTION		15				SHUTTLE TYPE	
FIRE DETECTION / SUPPRESSION			13		140		
SMOKE DETECTORS		7					
FIRE SUPPRESSION TANK		6				INCLUDES SUPPRESSANT	
FURNISHINGS AND EQUIPMENT			1100				
SEATS, PERSONNEL RESTRAINTS	2	200			135	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	3	300			175	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	3	300			215	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			250	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SLEEP STATIONS		0			0	NOT REQUIRED FOR TRANSFER	
INCIDENTAL EQUIPMENT	10	100			195	STORAGE FOR ASTRONAUT PERSONAL EFFECTS	
SUPPORT/INSTALLATION			135		170	10 % OF ECLSS	
CREW MOD DRY, EXCL GROWTH				23715	132		14.6
WEIGHT GROWTH MARGIN				3557	132	15 % OF DRY WT	
CREW MODULE DRY WEIGHT				27272	132		

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Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 11 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
NON- CARGO ITEMS				4266	167		
CREW, WITH EQUIPMENT			3000				
FLIGHT CREW / personal effects	2	600			135	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	3	900			175	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	3	900			215	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			250	90TH PERCENTILE + 107 lb ea.	
TOOLS, MISCELLANEOUS	0	0			0		
EVA SUITS, WITH EXPENDABLES	0	0			0		
PROPELLANT RESIDUALS			414				
OMS RESIDUALS - IN TANKS		73			45	0.3 FT3 PER TANK	
OMS RESIDUALS - IN LINES, ENGINES		132			45	8 FT EA, 5.0 IN DIA.	
OMS PRESSURANTS		92			115	0.0251 LB/LB PROPELLANT NITROGEN	
RCS RESIDUAL BI-PROP		46			185	RESIDUAL IN TANKS AND LINES	
RCS N2 PRESSURANT		18			115		
COLD GAS RESIDUALS		53			115		
PROPELLANT RESERVES			851				
OMS RESERVES		333			45	10% OF NOMINAL	
RCS RESERVES - BIPROP		269			185	20% OF NOMINAL PROPELLANT	
RCS RESERVES - COLD GAS		249			115	20% OF NOMINAL PROPELLANT	
PAYLOAD / CARGO				0		**NO CARGO CAPABILITY**	
CREW MODULE INERT WEIGHT				31538	137		

NON- PROPELLANT				855	147		
IN-FLIGHT LOSSES			334			(CR- 264 KW-HR; SS- 840 KW-HR)	
FUEL CELL NOMINAL O2		238			185	0.71 LB/ KW -HR	
FUEL CELL NOMINAL H2		30			185	0.09 LB/ KW-HR	
FUEL CELL O2 RESERVES		48			185	20% NOMINAL	
FUEL CELL H2 RESERVES		6			185	20% NOMINAL	
FUEL CELL RESIDUAL REACTANT		13			185	ESTIMATE	
LIFE SUPPORT CONSUMABLES			521				
O2 - CRYO STORAGE		34			185	METABOLIC CONSUMPT. (2 LB/M-DAY) +20%	
O2 - GAS FOR REPRESSURIZATION		15			40	1 repress contingency + leak (0.38 LB/DAY)	
O2 - CABIN PRESSURIZATION		14			40		
N2 - GAS FOR REPRESS, LOSSES		67			115	1 repress contingency + leak (1.26 LB/DAY)	
N2 - CABIN PRESSURIZATION		63			115		
FOOD - nominal		56			170	4 LB/M-DAY	
FOOD - contingency		80			170	4 LB/M-DAY -- 48 hr contingency	
POTABLE WATER - nominal		0			170	4 LB/M-DAY supplied by fuel cells	
POTABLE WATER - contingency		92			170	4 LB/M-DAY --48 HR CONTINGENCY + resid	
EQUIP COOLING FLUIDS - AMMONIA		45			30	COOLANT FOR LAUNCH & REENTRY COOLING ONLY + 20 %	
EQUIP COOLING FLUIDS - WATER		55			30	WATER FOR HI-LOAD COOLING + 20 %	

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Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 12 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
PROPELLANT - NOMINAL				**3983**	**65**		
RCS NOM PROPELLANT - BIPROP			472		185		
RCS NOM PROPELLANT - COLD GAS			178		115		
OMS NOMINAL PROPELLANT			3334		45	DELTA V AS SHOWN	
GROSS WEIGHT				**36377**	**129**		
ADAPTER / RADIATOR MODULE				**2522**	**-69**		
STRUCTURE			989		-69		
AFT ADAPTER INTERFACE RING	1	158				L=43 FT, A=3.0 IN2 ALUMINUM	
CREW MODULE INTERFACE RING	1	92				L=30.6 FT, A=2.5 IN2 ALUMINUM	
MINOR FRAMES	2	134				L=37.3 FT, A=1.5 IN2 ALUMINUM	
LONGERONS	6	257				L=11.9 FT, A=3.0 IN2 ALUMINUM	
INTERMEDIATE STRUTS / FTGS	18	248				L ave=7.1 FT, A=1.0 IN2 +1.0 LB FTGS ALUMINUM	
RADIATOR PANEL LINKAGE & HINGES	2	40					
LAUNCH / CREW MOD UMBIL PLATES	2	60					
THERMAL PROTECTION			71		-69	S= 1034 SF, @ 0.0685 PSF FOSR	
POWER DISTRIBUTION			188		-69		
WIRING, INCL GROUND UMBILICALS		150					
EQUIPMENT SUPPORT/INSTL		38				25 % OF WIRING ALUMINUM	
ECLSS RADIATOR PANELS			795		-69		
COOLANT IN PANELS - FREON		30					
FIXED PANELS	2	304				A=134 sf ea @ 1.14 psf ALUMINUM	
DEPLOYED PANELS	2	461				A=134 sf ea (134 sf ea side) @ 1.72 psf ALUMINUM	
OTHER - AUXILIARY SYSTEMS			150		-69		
LAUNCH VEHICLE SEPARATION	6	90				EXPLOSIVE BOLT SEPARATION	
CREW MODULE SEPARATION	6	60				EXPLOSIVE BOLT SEPARATION	
WEIGHT GROWTH MARGIN			329		-69	15 % OF HARDWARE	
GROSS WEIGHT				**38899**	**116**		
LAUNCH VEHICLE ADAPTER				**1956**	**-234**		
STRUCTURE			1363		-234	S= 545 SF @ 2.5 PSF ALUM SKIN/STR	
PROTECTION - THERMAL			0		-234		
POWER - WIRE HARNESS			188		-234	L= 8 FT, INCL CONNECTORS, ETC	
OTHER - CREW MOD SEPARATION SYS	6		150		-234	SEP BOLTS	
WEIGHT GROWTH MARGIN			255		-234	15 % OF HARDWARE	
BALLAST				**0**	**0**		
FWD NOSE BALLAST			0		340		
TOTAL LAUNCH WEIGHT				**40855**	**100**		

Table 21.3-8 Detailed Mass Properties for Configuration III (10 Person) (Page 13 of 13)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE	XCG	REMARKS	WG%
SEQUENCED MASS DATA					
TOTAL WEIGHT		40855	100		
SEPARATE FROM LAUNCH VEH ADAPTER		-1956	-234		
ON-PAD ABORT WEIGHT		38899	116		
JETTISON LAUNCH ESCAPE ENG, FEED		-2543	-33		
JETTISON LAUNCH ESCAPE THRUST STR		-78	-13		
ON-ORBIT WEIGHT		36278	127		
DELETE CONSUMABLES TO REENTRY		-69	123		
DELETE POWER FLUIDS TO REENTRY		-263	185		
DELETE NOMINAL RCS ON-ORBIT PROP		-340	185		
DELETE PROX OPS COLD GAS		-178	115		
DELETE OMS ON-ORBIT PROP		-3334	45		
SEPARATE SERVICE MODULE		0	0		
SEPARATE RADIATOR MODULE		-2522	-69		
BEGIN REENTRY WEIGHT		29572	152		
DELETE CONSUMABLES		-13	123		
DELETE REENTRY POWER FLUIDS		-5	185		
DELETE NOMINAL RCS REENTRY PROP		-132	185		
LANDING WEIGHT		29423	152		

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Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 1 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS) — **NOTE: ALL MASS IN POUNDS**

ITEM	QTY	CREW ROTATION VALUE			REMARKS		WG%
PERSONNEL			10				
CREW		2					
PASSENGERS		8					
MISSION DURATION (DAYS)			3.0				
ECLSS							
CLOSURE LEVEL			OPEN				
PRESSURIZED VOLUME -CABIN (FT3)			613.0		60% VOLUME, 71% AREA RATIO		
PRESSURIZED VOLUME -AIRLOCK (FT3)			0.0				
PRESS/REPRESS EVENTS			2.0				
CABIN LEAKAGE (%VOLUME/DAY)			2.0				
PROPULSION		Delta V	Isp,sec				
RCS - H2O2/RP		146	310				
COLD GAS - N2		10	60				
OMS - LO2/RP		989	315				
LES - Expend Liquid Pusher		606	310				
ON-PAD ABORT WEIGHT			32231				
ON-ORBIT WEIGHT			29611				
LANDING WEIGHT			23754				
DESIGN LANDING WEIGHT			23400				
STRUCTURE - TAIL GROUP				**445**			**15**
TIP FIN BASIC STRUCTURE			393				
CONTROL SURFACES			52				
STRUCTURE - BODY GROUP				**5422**			**15**
FWD FUSELAGE BASIC STRUCTURE			609			ALUM SKIN / STR	
MID FUSELAGE BASIC STRUCTURE			1028			ALUM SKIN / STR	
AFT FUSELAGE BASIC STRUCTURE			557			ALUM SKIN / STR	
THRUST STRUCTURE - OMS (FIXED)			272				
THRUST STRUTS	4	78			L=6.7 FT, A=2.0 IN2 +20%	ALUMINUM	
THRUST STR STABILIZING STRUTS	TBD	39					
ENG INTERFACE FTGS	3	9			ESTIMATE		
TANK SUPPORT STRUTS	8	66			L= 72 IN, A=1.0 IN2 + 1 LB FTGS EA	ALUMINUM	
TANK SWAY STRUTS	16	72			L=40 IN, A=1.0 IN2 + 1 LB FTG EA	ALUMINUM	
PRESS TANK SUPT FLANGES	8	8			ESTIMATE	ALUMINUM	
THRUST STRUCT. - LAUNCH ESCAPE (JETT)			68				
ENGINE THRUST STRUTS	3	29			L=5 FT, A=4.0 IN2 + 20%	ALUMINUM	
STABILIZING STRUTS, FTGS, ETC	TBD	15			ESTIMATE		
THRUST STRUCT SEPARATION BOLTS	3	24					
FWD FUSELAGE SECONDARY STRUCTURE			279				
WINDOW, THERMAL	4	29			S,ave=0.8 SF EA @ 9.0 PSF		
WINDOW, RETAINER	4	10					
DOCKING HATCH COVER	0	0					
DOCKING COVER HINGES, MECHANISM	0	0					
DOORS, FRAMES - NOSE LANDING GEA	1	57			S= 11.0 SF @ 5.2 PSF	ALUMINUM	
NOSE LANDING GEAR SUPPORT	1	103					
ACCESS PANELS	2	48			S= 8 SF EACH @3.0 PSF	ALUMINUM	
EQUIPMENT SUPPORT RACKS	2	32			S= 8 SF EA @ 2.0 PSF	ALUMINUM	

Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 2 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)
NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE		REMARKS		WG%
MID FUSELAGE SECONDARY STRUCT			354			
DOORS, FRAMES - MAIN LANDING GEAR	2	104		S= 10.0 SF EA.@ 5.2 PSF	ALUMINUM	
MAIN LANDING GEAR SUPPORT	2	206				
RMS GRAPPLE FITTING	2	44				
AFT FUSELAGE SECONDARY STRUCT			208			
SERVICE MODULE UMBILICAL PLATE	1	20				
LAUNCH/PROP MODULE UMBIL PLATE	1	20				
BODY FLAP	1	108		S= 12 SF @ 9.0 PSF	RCC/ INSTL	
BODY FLAP CLOSEOUT/HINGE SUPT	1	60		S=6.7 SF @ 9.0 PSF		
CREW MODULE BASIC STRUCTURE			1056		ALUMINUM SKIN / STRINGER	
CREW MODULE SECONDARY STRUCTURE			992		ALUMINUM SKIN / STRINGER	
INTERNAL EQUIPMENT BAY	1	84		S= 56 SF @ 1.5 PSF		
EQUIPMENT SUPPORT RACKS	2	150		S=100 SF @ 1.5 PSF		
WINDOWS	6	130		S= 0.8 SF EA @ 27 PSF		
WINDOWS, RETAINER	6	65				
DOCKING ADAPTER MECHANISM	1	340				
AIRLOCK INTERFACE RING	0	0		L= 13.0 FT, A= 2.5 IN2 + 20%	ALUMINUM	
TOP HATCH, STRUCTURE	1	58		36-IN DIA		
TOP HATCH, MECHANISM	1	32				
DOCKING HATCH, STRUCTURE	1	72		40-IN DIA, SHUTTLE-TYPE (8.7 sf)		
DOCKING HATCH, WINDOW & RETAINER	1	20				
DOCKING HATCH, MECHANISM	1	41				

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Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 3 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE			REMARKS	WG%
PROTECTION				**2286**		**15**
EXTERNAL TPS - WINGLETS			439			
EXTERNAL TPS - BODY			1541			
INTERNAL INSULATION / TCS			236			
PURGE AND VENT SYSTEM			51		SCALED FROM SHUTTLE	
DUCTING		21				
VALVES		20				
SUPPORT, INSTALLATION		10				
WINDOW / HATCH CONDITIONING			19		SCALED FROM SHUTTLE	
PLUMBING		7				
DESSICANT, VALVES, DISCONNECTS		8				
SUPPORT, INSTALLATION		4				
RECOVERY & AUXILIARY SYSTEMS				**1922**		**15**
DROGUE CHUTE SYSTEM			1334			
DROGUE CHUTES	1	320			FOR ABORT CONDITION OR BRAKED LANDING	
BACKUP DROGUE	1	320				
ABORT MAIN CHUTES	3	630				
PARACHUTE SUPT/INSTL		64			10 % OF SYSTEM	
LANDING SYSTEM			462			
NOSE LANDING GEAR	1	84			0.005 LB/LB DESIGN LANDING WT (MAX)	
MAIN LANDING GEAR	2	336			0.02 LB/LB DESIGN LANDING WT (MAX)	
LANDING GEAR SUPT/INSTL		42			10 % OF SYSTEM	
SEPARATION			126			
LAUNCH ESCAPE MOTOR SEPARATION	3	36				
LAUNCH VEHICLE SEP BOLTS	6	90				

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Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 4 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			REMARKS		WG%
PROPULSION - REACTION CONTROL				**882**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
THRUSTER MODULES - FORWARD			116				
THRUSTERS - RCS	10	83					
THRUSTERS - COLD GAS	6	22			MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTER MODULE SUPPORT	4	11			10 % OF SYS		
THRUSTER MODULES - AFT			97				
THRUSTERS - RCS	8	66					
THRUSTERS - COLD GAS	6	22			MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTER MODULE SUPPORT	4	9			10 % OF SYS		
PRESSURIZATION SYSTEM			21				
GN2 BOTTLE(S) - RCS	0	0			INCL IN COLD GAS SYSTEM		
REGULATORS	0	0			FAIRCHILD		
FILL & DRAIN DISCONNECTS	1	1			PYRONETICS		
MANIFOLD/PLUMBING		8			BOEING		
TANK VENT / RELIEF		9					
PRESS SYS SUPPORT		3			15 % OF SYS		
PROPELLANT SUPPLY - RCS			174				
TANKAGE - H2O2	2	48			31.0-IN DIAMETER SPHERICAL	NEW	
TANKAGE - RP	2	18			16.5-IN DIAMETER SPHERICAL	NEW	
VALVES	9	35			CONSOLIDATED CONTROLS		
MANIFOLD/PLUMBING	1	32			BOEING 304L SS		
TANK FILL, VENT & DRAIN	2	25					
PROPELLANT SUPPLY SUPPORT		16			10 % OF SYS		
PROPELLANT SUPPLY - PROX-OPS (fixed)			474				
N2 BOTTLE(S) - OMS, RCS, COLD GAS	4	280			15-IN ID X 74-IN LONG	KEVLAR O/W Ti	
VALVES	16	82			CONSOLIDATED CONTROLS		
FLIGHT DISCONNECT	1	1			PYRONETICS		
FILL / DRAIN DISCONNECT	4	4			PYRONETICS		
MANIFOLD/PLUMBING		34			BOEING 304L SS		
TANK VENT / RELIEF		14					
TANK SEPARATION	4	16			EXPLOSIVE BOLTS		
COLD GAS SUPPLY SUPPORT		43			10 % OF SYS		

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Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 5 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS		WG%
PROPULSION - ORBIT MANEUVER				**513**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
THRUSTER MODULES			165				
ENGINES	3	150					
ENGINE MOUNT	3	15					
PRESSURIZATION SYSTEM			60				
GN2 BOTTLES - OMS	0	0			INCL IN COLD GAS SYSTEM		
GAS VALVES	4	18			MOOG		
REGULATORS	2	9			FAIRCHILD		
FILL & DRAIN DISCONNECTS	2	2			PYRONETICS		
MANIFOLD/PLUMBING		8			BOEING 304L SS		
BOTTLE VENT / RELIEF		17			FAIRCHILD		
PRESS SYSTEM SUPPORT		6			15 % OF OMS		
PROPELLANT SUPPLY - OMS			288				
LO2 SYSTEM - TANK	2	82			44.0 in ID TANK, WITH INSULATION	ALUMINUM	
LO2 SYSTEM - VALVES	4	16					
LO2 SYSTEM - MANIFOLD	1	16			8 FT @ 2.5 LB/FT	ALUMINUM	
LO2 SYSTEM - FILL, DRAIN, VENT	1	24					
LO2 SYSTEM - SUPPORT, INSTL		21			15 % OF OMS		
RP SYSTEM - TANK	2	56			35.0 in ID TANK, WITH INSULATION	ALUMINUM	
RP SYSTEM - VALVES	4	16					
RP SYSTEM - MANIFOLD	1	16			8 FT @ 2.5 LB/FT	ALUMINUM	
RP SYSTEM - FILL, DRAIN, VENT	1	24					
RP SYSTEM - SUPPORT, INSTL		17			15 % OF OMS		
PROPULS - LAUNCH ESCAPE SYSTEM				**2211**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
LAUNCH ESC MOTOR / TURBOPUMP (JETT)			1410				
TURBOPUMP ASSEMBLY	2	1140			ESTIMATE		
ENGINE	1	250			ESTIMATE		
ENGINE / TURBOPUMP MOUNT	1	20					
TURBOPUMP GAS GENERATOR (JETT)			360				
GAS GENERATOR	1	200			ESTIMATE		
GAS GENERATOR TANKAGE (WET)	1	160			ESTIMATE		
PROPELLANT SUPPLY (JETT)			71				
LO2 SYSTEM - DISCONNECT	1	12			DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	29			DIA = 5.0 IN, L=5 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	18			DIA = 5.0 IN, L=5 FT @ 3.5 LB/FT	ALUMINUM	
PROPELLANT SUPPLY (FIXED)			169				
LO2 SYSTEM - DISCONNECT	1	12			DIA=5.0 IN		
LO2 SYSTEM - VALVE	2	40			DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	40			DIA = 5.0 IN, L=7 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			DIA=5.0 IN		
RP SYSTEM - VALVE	2	40			DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	25			DIA = 5.0 IN, L=7 FT @ 3.5 LB/FT	ALUMINUM	
EQUIPMENT SUPPORT/INSTL			201		10 % OF EQUIPMENT		

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Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 6 of 12)

GROUP WEIGHT STATEMENT Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)					NOTE: ALL MASS IN POUNDS	
	CREW ROTATION					
ITEM	QTY	VALUE			REMARKS	WG%
POWER - ELECTRICAL				2142		15
POWER SUPPLY			1348		FUEL CELL SYSTEM - 6 KW NOM, 9 KW PEAK TOTAL	
FUEL CELLS	2	361			Reduced Shuttle Cells - 2 of 3 to supply sustained power	
BATTERIES	6	432			Contingency only - 48 kw-hr LI-SOCL2	
O2 TANKAGE (EPS & ECLSS)	2	110			21.0 in ID VACUUM -JACKETED TANK	
H2 TANKAGE	2	116			26.0 in ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	4	12				
REACTANT RELIEF, VENT PLUMBING	4	64				
REACTANT SUPPLY PLUMBING	4	20				
REACTANT SUPPLY VALVES, DISC	4	12				
COOLANT PLUMBING		45			INCL. 30 LB FLUIDS	
WASTE WATER TANK		0			INCL IN WATER MANAGEMENT	
POWER SUPPLY SUPT/INSTL		176			15 % OF SYS	
POWER DIST EQUIP			169			
POWER DISTRIBUTION PANELS	3	99				
10VDC POWER SUPPLY	3	1				
EXTERIOR LIGHTS		15			ESTIMATE	
INTERIOR LIGHTS		20			ESTIMATE	
POWER DISTRIBUTION SUPT/INSTL		34			25 % OF SYS	
WIRING			625		ESTIMATE	
POWER DISTR. WIRE HARNESSES		350				
INSTRUMENTATION WIRING		100				
ELECTRICAL CONNECTORS		50			BULKHEAD FEEDTHRU PLATES	
HARNESS SUPT/INSTL		125			25 % OF SYS	
SURFACE CONTROLS				242		15
RUDDER ACTUATION			121		DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110				
ACTUATOR SUPT/INSTL		11			10 % OF SYS	
BODY FLAP ACTUATION			121		DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110				
ACTUATOR SUPT/INSTL		11			10 % OF SYS	

Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 7 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
AVIONICS				**1686**		**15**
GUIDANCE, NAVIGATION AND CONTROL			274			
FAULT-TOLERANT NAVIGATOR	1	50				
GPS RECEIVER	2	12				
GPS ANTENNAS	2	10				
HORIZON SCANNER	2	12				
RADAR ALTIMETER	2	10				
RUDDER DRIVER	1	45				
BODY FLAP DRIVER	1	45				
RCS/ OMS VALVE DRIVER	2	90				
RENDEVOUS AND DOCK			133			
RENDEVOUS RADAR	1	30				
RADAR SIGNAL PROCESSOR	1	70				
ANTENNA	1	8				
ANTENNA MAST, DEPLOYMENT MECHS	1	25				
VEHICLE HEALTH MONITORING			75		SENSORS INCL IN INSTRUMENTATION COUNT	
MASS MEMORY	3	75				
COMMUNICATIONS AND TRACKING			238			
CENTRAL DATA FORMATTER	1	27				
TRANSPONDER	1	16				
POWER AMP	1	18				
DIPLEXER, RF SWITCH	1	3				
AUDIO	1	40				
UHF TRANSCEIVER	1	20				
ANTENNAS	3	24				
SEARCH AND RESCUE RADIO	1	40			ESTIMATED	
SIGNAL CABLING		50			ESTIMATED	
CONTROLS AND DISPLAYS			185			
RECONFIG DISPLAYS / CONTROL UNITS	5	50				
ELECTRONIC INTERFACES	3	75				
RECONFIG. PUSH-BUTTON PANEL	3	30				
RMS WORKSTATION	0	0			ESTIMATE FOR SERVICING MISSION	
HAND CONTROLLERS	2	30				
INSTRUMENTATION			83			
SENSOR INTERFACE UNIT (SIU)	60	30				
NETWORK INTERFACE UNIT (NIU)	2	3				
SENSORS, INSTRUMENTATION	700	50				
DATA HANDLING			463			
FAULT TOLERANT PROCESSOR	3	99				
MASS MEMORY	3	75				
DATA BUS COUPLERS	60	30			ESTIMATED	
MDM	7	259				
STRUCTURES/MECHS CONTROLS			82			
CHUTE, LANDING GEAR CONTROLLER	1	61				
LASER FIRING UNIT	2	20				
LASER INITIATORS	5	1				
AVIONICS SUPT/INSTL			153		10 % OF AVIONICS	

BOEING

Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 8 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
ENVIRONMENTAL CONTROL				**1311**		**15**
CABIN AND PERSONNEL SYSTEM			350			
O2 TANKAGE - CRYO STORAGE	0	0			INCL IN FUEL CELL REACTANT STORAGE	
O2 TANKAGE - (GAS FOR REPRESS)	1	15			Kevlar / Inconel	
N2 TANKAGE - (GAS FOR REPRESS)	2	58			Kevlar / Titanium	
PRESS PLUMBING		12				
CABIN PRESS & COMPOSITION CNTRLS		52			VALVES, VENT RELIEF VALVES, ETC	
CO2 REMOVAL - 2-BED LIOH		11			LIOH CANISTER UNIT - 2 CANISTER UNIT	
LIOH CANISTER STORAGE - NOMINAL		31			(7.0 LB/2-PERSON-DAY)	
LIOH CANISTER STORAGE - CONTING.		42			48-HR @(7.0 LB/2-PERSON-DAY)	
TEMP AND HUMIDITY CONTROL		102			FANS/SEPARATORS, HEAT EXCHANGER, ETC	
TRACE CONTAMINANT CONTROL		7			CANISTER FOR IMPURITY REMOVAL	
DUCTING, MISC		20			FANS INCLUDED IN TEMPERATURE CONTROL	
EQUIPMENT COOLING			209			
EQUIPMENT COLD PLATES		120			S= 60 SF @ 2.0 PSF	
AVIONICS COOLING ASSY		28			INCL HX, FANS, DUCTING	
IMU HEAT EXCHANGER ASSY	1	31				
PLUMBING		20				
DUCTING, MISC		10			FANS INCLUDED IN TEMPERATURE CONTROL	
HEAT TRANSFER WATER LOOP			141			
HEAT EXCHANGER - POTABLE WATER	1	17			BASED ON SHUTTLE	
PRIMARY, SECONDARY WATER PUMPS		78				
PLUMBING		21				
COOLANT IN LOOP - WATER		25				
HEAT TRANSFER FREON LOOP			270			
HEAT EXCHANGER - WATER-FREON	1	50			BASED ON SHUTTLE	
HEAT EXCHANGER - GSE	1	50			BASED ON SHUTTLE	
HEAT EXCHANGER - FUEL CELL	1	50			BASED ON SHUTTLE	
FREON PUMP PACKAGE	2	90				
COOLANT IN LOOP - FREON		30				
HEAT REJECTION			222			
AMMONIA BOILER ASSEMBLY		45			INCL AMMONIA TANK, HEAT EXCHNGR, VENT, VALVES	
COOLANT TANKAGE - WATER		14				
FLASH EVAPORATOR - WATER		58			FROM SHUTTLE	
TOPPING DUCT ASSEMBLY		78				
HIGH LOAD DUCT ASSEMBLY		27				
RADIATOR PANELS			0		INCL ON AFT ADAPTER	
ECLSS SUPT/INSTL			119		10 % OF ECLSS	

Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 9 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS) — **NOTE: ALL MASS IN POUNDS**

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
PERSONNELPROVISIONS				1022		15
FOOD MANAGEMENT			117			
GALLEY		0			GALLEY UNIT, WITH WATER DISPENSER	
FOOD STORAGE UNITS		117				
WATER MANAGEMENT			52			
WATER STORAGE TANK	2	17			FOR POTABLE WATER STORAGE	
HANDWASH - WET WIPES		2				
WATER DISPENSER		23			WATER DISPENSER ONLY	
PLUMBING, VALVES, ETC		10				
WASTE MANAGEMENT			47			
WASTE WATER TANK	2	17				
COMMODE SYSTEM		15			installation scar only for crew rotation	
EMERGENCY WASTE COLLECTION		15			SHUTTLE TYPE	
FIRE DETECTION / SUPPRESSION			13			
SMOKE DETECTORS		7				
FIRE SUPPRESSION TANK		6			INCLUDES SUPPRESSANT	
FURNISHINGS AND EQUIPMENT			700			
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS					INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SLEEP STATIONS		0			NOT REQUIRED FOR TRANSFER	
INCIDENTAL EQUIPMENT	10	100			STORAGE FOR ASTRONAUT PERSONAL EFFECTS	
SUPPORT/INSTALLATION			93		10 % OF ECLSS	
CREW MOD DRY, EXCL GROWTH				20084		14.7
WEIGHT GROWTH MARGIN				3013	**15 % OF DRY WT**	
CREW MODULE DRY WEIGHT				23097		

Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 10 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
NON- CARGO ITEMS				**2932**		
CREW, WITH EQUIPMENT			1800			
FLIGHT CREW / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects					90TH PERCENTILE + 107 lb ea.	
TOOLS, MISCELLANEOUS	0	0				
EVA SUITS, WITH EXPENDABLES	0	0				
PROPELLANT RESIDUALS			388			
OMS RESIDUALS - IN TANKS		73			0.3 FT3 PER TANK	
OMS RESIDUALS - IN LINES, ENGINES		132			8 FT EA, 5.0 IN DIA.	
OMS PRESSURANTS		75			0.0251 LB/LB PROPELLANT NITROGEN	
RCS RESIDUAL BI-PROP		46			RESIDUAL IN TANKS AND LINES	
RCS N2 PRESSURANT		18				
COLD GAS RESIDUALS		44				
PROPELLANT RESERVES			744			
OMS RESERVES		272			10% OF NOMINAL	
RCS RESERVES - BIPROP		269			20% OF NOMINAL PROPELLANT	
RCS RESERVES - COLD GAS		203			20% OF NOMINAL PROPELLANT	
PAYLOAD / CARGO				**0**	**NO CARGO CAPABILITY**	
CREW MODULE INERT WEIGHT				**26029**		

ITEM	QTY	VALUE			REMARKS	WG%
NON- PROPELLANT				**694**		
IN-FLIGHT LOSSES			334		(CR- 264 KW-HR; SS- 840 KW-HR)	
FUEL CELL NOMINAL O2		238			0.71 LB/ KW -HR	
FUEL CELL NOMINAL H2		30			0.09 LB/ KW-HR	
FUEL CELL O2 RESERVES		48			20% NOMINAL	
FUEL CELL H2 RESERVES		6			20% NOMINAL	
FUEL CELL RESIDUAL REACTANT		13			ESTIMATE	
LIFE SUPPORT CONSUMABLES			360			
O2 - CRYO STORAGE		24			METABOLIC CONSUMPT. (2 LB/M-DAY) +20%	
O2 - GAS FOR REPRESSURIZATION		9			1 repress contingency + leak (0.38 LB/DAY)	
O2 - CABIN PRESSURIZATION		8				
N2 - GAS FOR REPRESS, LOSSES		40			1 repress contingency + leak (1.26 LB/DAY)	
N2 - CABIN PRESSURIZATION		36				
FOOD - nominal		40			4 LB/M-DAY	
FOOD - contingency		48			4 LB/M-DAY -- 48 hr contingency	
POTABLE WATER - nominal		0			4 LB/M-DAY supplied by fuel cells	
POTABLE WATER - contingency		55			4 LB/M-DAY --48 HR CONTINGENCY + resid	
EQUIP COOLING FLUIDS - AMMONIA		45			COOLANT FOR LAUNCH & REENTRY COOLING ONLY + 20 %	
EQUIP COOLING FLUIDS - WATER		55			WATER FOR HI-LOAD COOLING + 20 %	

BOEING

Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 11 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS) — NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			REMARKS	WG%
PROPELLANT - NOMINAL				3251		
RCS NOM PROPELLANT - BIPROP			385			
RCS NOM PROPELLANT - COLD GAS			145			
OMS NOMINAL PROPELLANT			2721		DELTA V AS SHOWN	
GROSS WEIGHT				29975		
ADAPTER / RADIATOR MODULE				2256		
STRUCTURE			989			
AFT ADAPTER INTERFACE RING	1	158			L=43 FT, A=3.0 IN2 ALUMINUM	
CREW MODULE INTERFACE RING	1	92			L=30.6 FT, A=2.5 IN2 ALUMINUM	
MINOR FRAMES	2	134			L=37.3 FT, A=1.5 IN2 ALUMINUM	
LONGERONS	6	257			L=11.9 FT, A=3.0 IN2 ALUMINUM	
INTERMEDIATE STRUTS / FTGS	18	248			L ave=7.1 FT, A=1.0 IN2 +1.0 LB FTGS ALUMINUM	
RADIATOR PANEL LINKAGE & HINGES	2	40				
LAUNCH / CREW MOD UMBIL PLATES	2	60				
THERMAL PROTECTION			71		S= 1034 SF, @ 0.0685 PSF FOSR	
POWER DISTRIBUTION			188			
WIRING, INCL GROUND UMBILICALS		150				
EQUIPMENT SUPPORT/INSTL		38			25 % OF WIRING	
ECLSS RADIATOR PANELS			564		ALUMINUM	
COOLANT IN PANELS - FREON		30				
FIXED PANELS	2	304			A=134 sf ea @ 1.14 psf ALUMINUM	
DEPLOYED PANELS	2	230			A=67 sf ea (67 sf ea side) @ 1.72 psf ALUMINUM	
OTHER - AUXILIARY SYSTEMS			150			
LAUNCH VEHICLE SEPARATION	6	90			EXPLOSIVE BOLT SEPARATION	
CREW MODULE SEPARATION	6	60			EXPLOSIVE BOLT SEPARATION	
WEIGHT GROWTH MARGIN			294		15 % OF HARDWARE	
GROSS WEIGHT				32231		
LAUNCH VEHICLE ADAPTER				1956		
STRUCTURE			1363		S= 545 SF @ 2.5 PSF ALUM SKIN/STR	
PROTECTION - THERMAL			0			
POWER - WIRE HARNESS			188		L= 8 FT, INCL CONNECTORS, ETC	
OTHER - CREW MOD SEPARATION SYS	6		150		SEP BOLTS	
WEIGHT GROWTH MARGIN			255		15 % OF HARDWARE	
BALLAST				0		
FWD NOSE BALLAST			0			
TOTAL LAUNCH WEIGHT				34187		

Table 21.3-9 Detailed Mass Properties for Configuration III (6 Persons) (Page 12 of 12)

GROUP WEIGHT STATEMENT
Lifting Body PLS Concept #3 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE	REMARKS	WG%
SEQUENCED MASS DATA				
TOTAL WEIGHT		34187		
SEPARATE FROM LAUNCH VEH ADAPTER		-1956		
ON-PAD ABORT WEIGHT		32231		
JETTISON LAUNCH ESCAPE ENG, FEED		-2543		
JETTISON LAUNCH ESCAPE THRUST STR		-78		
ON-ORBIT WEIGHT		29611		
DELETE CONSUMABLES TO REENTRY		-69		
DELETE POWER FLUIDS TO REENTRY		-263		
DELETE NOMINAL RCS ON-ORBIT PROP		-278		
DELETE PROX OPS COLD GAS		-145		
DELETE OMS ON-ORBIT PROP		-2721		
SEPARATE SERVICE MODULE		0		
SEPARATE RADIATOR MODULE		-2256		
BEGIN REENTRY WEIGHT		23879		
DELETE CONSUMABLES		-13		
DELETE REENTRY POWER FLUIDS		-5		
DELETE NOMINAL RCS REENTRY PROP		-107		
LANDING WEIGHT		23754		

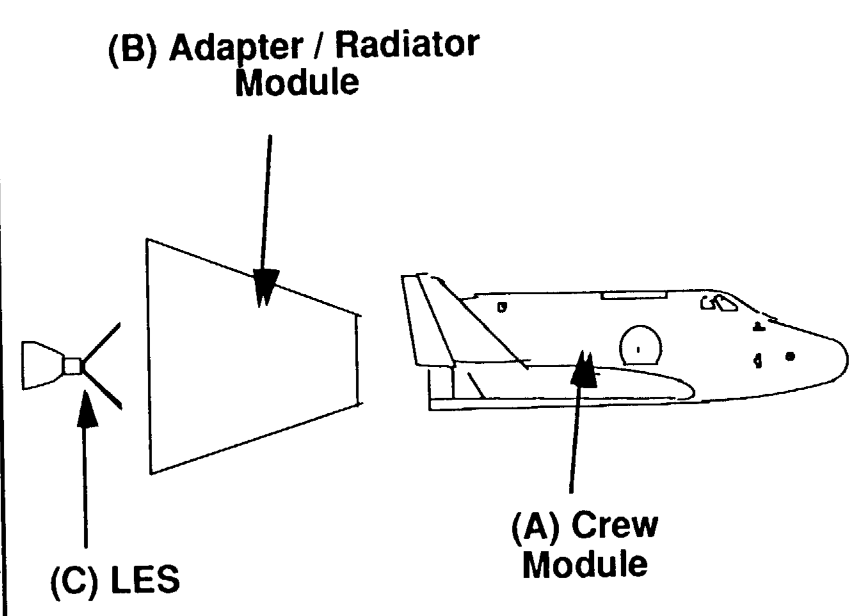
Finally, Configuration IV mass properties can be seen in summary and in detail as Tables 21.3-10 and 21.3-11 respectively. The six person version is summarized as Table 21.3-12.

Table 21.3-10 Summary Weight Statement - Configuration IV

Crew / Passengers: 2 / 8 **Mission Duration :** 72 Hour

Functional System	A	B	C	D
1. Structure	7946	989	155	
2. Protection	3556	71		
3. Propulsion	1559		2211	
4. Power - Electrical	2205	188		
5. Control	363			
6. Avionics	1736			
7. Environment	1471	795		
8. Other - Personnel Provisions	1486			
Other - Landing, Aux Systems	2450	150		
9. Weight Growth Margin	3416	329	355	
Dry Mass	26188	2522	2721	
10. Non- Cargo (See Note 1)	4301	0		
11. Cargo	0	0		
Inert Mass	30489	2522	2721	
12. Non- Propellant Consumables	855			
13. Propellant - Nominal	4177	0		
Gross Mass	35521	2522	2721	
	38043		2721	
Total Mass	40764			

Configuration: Winged Vehicle (Tile TPS)



Notes:
A Crew Module
B Adapter / Radiator Module
C Launch Escape System (LES)
D Fwd Fairing

All Mass in Pounds

1 Includes Flight Crew + Equipment (€00 Lb), Passengers +Equip (2400 Lb), And Propellant Reserves / Residuals

Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 1 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PERSONNEL			10					
CREW		2						
PASSENGERS		8						
MISSION DURATION (DAYS)			3.0					
ECLSS								
CLOSURE LEVEL			OPEN					
PRESSURIZED VOLUME -CABIN (FT3)			1031.0					
PRESSURIZED VOLUME -AIRLOCK (FT3)			0.0					
PRESS/REPRESS EVENTS			2.0					
CABIN LEAKAGE (%VOLUME/DAY)			2.0					
PROPULSION		Delta V	Isp,sec					
RCS - H2O2/RP		146	310					
COLD GAS - N2		10	60					
OMS - LO2/RP		989	315					
LES - Expend Liquid Pusher		606	310					
ON-PAD ABORT WEIGHT			40765					
ON-ORBIT WEIGHT			38045					
LANDING WEIGHT			30996					
DESIGN LANDING WEIGHT			30000					
STRUCTURE - WING GROUP				**1207**	**269**			**15**
WING BASIC STRUCTURE			752					
LEADING EDGE	2	62			355	S= 8.5 SF EA. @ 3.7 PSF	TITANIUM	
INTERMED SECTION, EXCL MLG PROVIS	2	136			322	S= 18.5 SF EA. @ 3.7 PSF	ALUMINUM	
TORQUE BOX	2	478			245	S= 42.0 SF EA. @ 5.7 PSF	ALUMINUM	
TRAILING EDGE - FIXED	2	38			223	S= 5.2 SF EA. @ 3.7 PSF	TITANIUM	
TRAILING EDGE - HINGED SEAL PANEL	2	38			223	S= 5.2 SF EA. @ 3.7 PSF	TITANIUM	
WING FOLDING / LATCH MECHANISMS		0				REQUIREMENT TBD		
WING SECONDARY STRUCTURE			299					
DOORS, FRAMES - MAIN LANDING GEAR	2	53			308	S= 13.3 SF EA. @ 2.0 PSF	ALUMINUM	
MAIN LANDING GEAR SUPPORT	2	210			308	0.007" design landing wt		
FAIRING - wing-to-body		30			316	S= 10 SF EA. @ 1.5 PSF		
INTERIOR FINISH		6			275	S= 414 SF @ 0.015 PSF		
CONTROL SURFACES			156					
ELEVON	2	138			209	S= 17.2 SF EA. @ 4.0 PSF	TITANIUM	
ELEVON SUPPORT HINGES, MECHANISM	2	12			223	7% OF ELEVON MASS		
ELEVON ACTUATOR FITTINGS	2	6			223	3% OF ELEVON MASS		
STRUCTURE - TAIL GROUP				**356**	**189**			**15**
TIP FIN BASIC STRUCTURE			216					
LEADING EDGE	2	18			225	S= 2.5 SF EA. @ 3.5 PSF	TITANIUM	
TORQUE BOX	2	180			202	S= 25.7 SF EA. @ 3.5 PSF	ALUMINUM	
TRAILING EDGE - FIXED	2	18			180	S= 2.5 SF EA. @ 3.5 PSF	TITANIUM	
CONTROL SURFACES			140					
RUDDER	2	130			168	S= 16.4 SF EA. @ 4.0 PSF	TITANIUM	
RUDDER SUPPORT MECHANISMS	2	7			180	7% OF RUDDER MASS		
RUDDER ACTUATOR/FITTINGS	2	3			180	3% OF RUDDER MASS		

BOEING

Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 2 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
STRUCTURE - BODY GROUP				**6538**	**365**			**15**
FWD FUSELAGE BASIC STRUCTURE			663			(X.484- X.580)	ALUM SKIN / STR	
FWD BULKHEAD - STA. 580	1	32			580	S= 16.0 SF @ 2.0 PSF		
MAJOR FRAME - STA. 484	1	93			484	L = 25.5 ft, A=3.0 in2		
MINOR FRAMES	3	115			532	L, ave = 21.0 ft, A=1.5 in2		
JOINTS, SPLICES, FASTENERS		36			525	15% OF FRAMES, BULKHEADS		
COVER PANELS, UPPER (LESS ACCESS)		53			530	S=31 SF @ 1.7 PSF		
COVER PANELS, LWR (LESS LG DOOR)		158			530	S=93 SF @ 1.7 PSF		
LONGERONS - FWD BODY	3	58			532	L= 8.0 FT ea, A=2.0 IN2		
NOSE WHEEL WELL & FRAMES	1	60			545	S=20 SF @ 3.0 PSF		
NOSE WHEEL SUPT STRUTS	4	58			545	L= 6.0 FT, A=2.0 IN2		
MID FUSELAGE BASIC STRUCTURE			1478			(X.245- X.484)	ALUM SKIN / STR	
MAJOR FRAME - FWD WING ATTACH	1	93			415	L = 25.5 ft, A=3.0 in2		
MINOR FRAMES	8	247			365	L = 25.5 ft, A=1.0 in2		
JOINTS, SPLICES, FASTENERS		51			365	15% OF FRAMES, BULKHEADS		
COVER PANELS, UPPER		408			365	S=240 SF @ 1.7 PSF		
COVER PANELS, LOWER		501			365	S=295 SF @ 1.7 PSF		
LONGERONS - MID BODY	3	145			365	L= 20.0 FT ea, A=2.0 IN2		
FTGS, CABIN ATTACHMENT	22	33			365			
AFT FUSELAGE BASIC STRUCTURE			785			(X.174- X.245)	ALUM SKIN / STR	
BULKHEAD - MAIN WING CARRY-THRU	1	130			245	S= 25 SF @ 5.2 PSF		
AFT BULKHEAD - STA. 195	1	134			195	S= 79 SF @ 1.7 PSF		
MINOR FRAMES - AFT BODY	3	153			210	L, ave=28.0 ft, A=1.5 in2		
JOINTS, SPLICES, FASTENERS		42			210	15% OF FRAMES, BULKHEADS		
COVER PANELS, UPPER		119			210	S=70 SF @ 1.7 PSF		
COVER PANELS, LOWER		163			210	S=96 SF @ 1.7 PSF		
LONGERONS - AFT BODY	3	44			210	L=6.0 FT, A=2.0 IN2		
THRUST STRUCTURE - OMS (FIXED)			242					
THRUST STRUTS	4	58			220	L=5 FT, A=2.0 IN2 +20%	ALUMINUM	
THRUST STR STABILIZING STRUTS	TBD	29			220			
ENG INTERFACE FTGS	3	9			195	ESTIMATE		
TANK SUPPORT STRUTS	8	66			220	L= 72 IN, A=1.0 IN2 + 1 LB FTGS EA	ALUMINUM	
TANK SWAY STRUTS	16	72			220	L=40 IN, A=1.0 IN2 + 1 LB FTG EA	ALUMINUM	
PRESS TANK SUPT FLANGES	8	8			220	ESTIMATE	ALUMINUM	
THRUST STRUCT. - LAUNCH ESCAPE (JETT)			155					
ENGINE THRUST STRUTS	3	87			175	L=15 FT, A=4.0 IN2 + 20%	ALUMINUM	
STABILIZING STRUTS, FTGS, ETC	TBD	44			175	ESTIMATE		
THRUST STRUCT SEPARATION BOLTS	3	24			190			
FWD FUSELAGE SECONDARY STRUCTURE			288					
DOORS, FRAMES - NOSE LANDING GEA	1	57			545	S= 11.0 SF @ 5.2 PSF	ALUMINUM	
NOSE LANDING GEAR SUPPORT	1	103			545			
ACCESS PANELS	2	96			565	S= 16 SF EACH @3.0 PSF	ALUMINUM	
EQUIPMENT SUPPORT RACKS	2	32			565	S= 8 SF EA @ 2.0 PSF	ALUMINUM	
MID FUSELAGE SECONDARY STRUCT			302					
WINDOW, THERMAL	6	43			435	S,ave=0.8 SF EA @ 9.0 PSF		
WINDOW, RETAINER	6	15			435			
DOCKING HATCH COVER	1	150			395	S= 50 SF @ 3.0 PSF		
DOCKING COVER HINGES, MECHANISM	1	50			395	ESTIMATE		
RMS GRAPPLE FITTING	2	44			410			
AFT FUSELAGE SECONDARY STRUCT			325					
SERVICE MODULE UMBILICAL PLATE	1	20			240			
LAUNCH/PROP MODULE UMBIL PLATE	1	20			240			
BODY FLAP	1	225			200	S= 25 SF @ 9.0 PSF	RCC/ INSTL	
BODY FLAP CLOSEOUT/HINGE SUPT	1	60			220	S=6.7 SF @ 9.0 PSF		

Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 3 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
CREW MODULE BASIC STRUCTURE			1292				ALUMINUM SKIN / STRINGER	
BULKHEAD, FWD	1	61			470	S=81 SF @ 0.75 PSF	ALUMINUM	
BULKHEAD, AFT	1	61			260	S= 81 SF @ 0.75 PSF	ALUMINUM	
BULKHEAD, CUPOLA AFT	1	18			420	S= 5 SF @ 3.5 PSF		
MINOR FRAMES, CABIN	8	353			367	L, ave= 24.3 FT , A= 1.5 IN2	ALUMINUM	
COVER PANELS, UPPER		267			367	S=157 SF @ 1.7 PSF	ALUMINUM	
COVER PANELS, LOWER		291			367	S= 171 SF @ 1.7 PSF	ALUMINUM	
FLOORING, EQUIP SUPT		208			367	S= 104 SF @ 2.0 PSF	ALUMINUM	
FTGS, CABIN ATTACHMENT	22	33			367			
CREW MODULE SECONDARY STRUCTURE			1008				ALUMINUM SKIN / STRINGER	
INTERNAL EQUIPMENT BAY	1	100			460	S= 67 SF @ 1.5 PSF		
EQUIPMENT SUPPORT RACKS	2	150			460	S=100 SF @ 1.5 PSF		
WINDOWS	6	130			435	S= 0.8 SF EA @ 27 PSF		
WINDOWS, RETAINER	6	65			435			
DOCKING ADAPTER MECHANISM	1	340			390			
AIRLOCK INTERFACE RING	0	0			390	L= 13.0 FT, A= 2.5 IN2 + 20%	ALUMINUM	
TOP HATCH, STRUCTURE	1	58			390	36-IN DIA		
TOP HATCH, MECHANISM	1	32			390			
SIDE HATCH, STRUCTURE	1	72			390	40-IN DIA, SHUTTLE-TYPE		
SIDE HATCH, WINDOW & RETAINER	1	20			390			
SIDE HATCH, MECHANISM	1	41			390			
PROTECTION				**3556**	**359**			**15**
EXTERNAL TPS - WING			1215					
FIXED WING LEADING EDGE - RCC		86			355	S= 8.5 SF EA. @ 5.0 PSF	RCC/INSTL	
LEADING EDGE, INSTL HDWARE		52			355	60% OF RCC WEIGHT		
LEADING EDGE, BULK INSULATION		102			355	S=8.5 SF EA.@ 6.0 PSF		
MAIN LANDING GEAR DOORS - HRSI		93			308	S=13.3 SF EA.@ 3.5 PSF, incl closeouts	FRCI-12 w/SiC cover	
FIXED WING UPPER SURFACE - LRSI		187			290	S= 66.2 SF EA. @ 1.41 PSF	FRCI-12	
FIXED WING LOWER SURFACE - HRSI		389			290	S= 66.2 SF EA. @ 2.94 PSF	FRCI-12 w/SiC cover	
ELEVON - UPPER SURFACE - LRSI		48			209	S= 17.2 SF EA. @ 1.41 PSF	FRCI-12	
ELEVON - LOWER SURFACE - HRSI		100			209	S= 17.2 SF EA. @ 2.94 PSF	FRCI-12 w/SiC cover	
THERMAL BARRIERS / SEALS		158			223	15% OF TPS WEIGHTS		
EXTERNAL TPS - TIP FINS			323					
TIP FIN LEADING EDGE - HRSI		30			202	S= 5.0 SF EA. @ 2.94 PSF	FRCI-12 w/SiC cover	
TIP FIN SURFACE - LRSI		159			202	S= 56.4 SF EA. @ 1.41 PSF	FRCI-12	
RUDDER SURFACE - LRSI		92			168	S= 32.8 SF EA. @ 1.41 PSF	FRCI-12	
THERMAL BARRIERS / SEALS		42			180	15% OF TPS WEIGHTS		
EXTERNAL TPS - BODY			1673					
NOSE CAP, PANELS - RCC		125			590	S= 25.0 SF @ 5 PSF	RCC/INSTL	
NOSE CAP, INSTL HDWARE		75			580	60% OF RCC WEIGHT		
NOSE CAP, BULK INSULATION		81			580	S=13.5 SF @ 6.0 PSF		
BODY TPS - HRSI (FWD)		400			500	S=136 SF @ 2.94 PSF	FRCI-12 w/SiC cover	
BODY TPS - HRSI (MID/AFT)		479			336	S=163 SF @ 2.94 PSF	FRCI-12 w/SiC cover	
LANDING PAD DOOR TPS - HRSI		39			545	S=11 SF @ 3.5 PSF, incl closeouts	FRCI-12 w/SiC cover	
BODY TPS - LRSI (FWD)		92			500	S=65 SF @ 1.41 PSF	FRCI-12	
BODY TPS - LRSI (MID)		99			373	S=70 SF @ 1.41 PSF	FRCI-12	
BODY TPS - FRSI		197			353	S=378 SF @ .522 PSF	Rigid TABI	
ACCESS PANEL TPS - LRSI		45			565	S= 32 SF @ 1.41 PSF	FRCI-12	
AFT BULKHEAD TPS - FRSI		41			195	S=79 SF @ 0.522 PSF	Rigid TABI	

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Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 4 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			XCG	REMARKS		WG%
INTERNAL INSULATION / TCS			264					
BULK INSULATION - FWD BODY		55			530	S= 156 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSULATION - FWD BODY		11			530	S= 156 SF @ 0.07 PSF	MLI	
BULK INSULATION - CREW MODULE		165			365	S= 470 SF @ 0.35 PSF	BULK INSUL	
MULTI-LAYER INSUL. - CREW MODULE		33			365	S= 470 SF @ 0.07 PSF	MLI	
PURGE AND VENT SYSTEM			63			SCALED FROM SHUTTLE		
DUCTING		30			360			
VALVES		20			360			
SUPPORT, INSTALLATION		13			360			
WINDOW / HATCH CONDITIONING			19			SCALED FROM SHUTTLE		
PLUMBING		7			435			
DESSICANT, VALVES, DISCONNECTS		8			435			
SUPPORT, INSTALLATION		4			435			
RECOVERY & AUXILIARY SYSTEMS				**2450**	**226**			**15**
DROGUE CHUTE SYSTEM			1727					
DROGUE CHUTES	1	390			185	FOR ABORT AND BRAKED LANDING		
BACKUP DROGUE	1	390			185			
ABORT MAIN CHUTE	1	790			185			
PARACHUTE SUPT/INSTL		157			185		10 % OF SYSTEM	
LANDING SYSTEM			593					
NOSE LANDING GEAR	1	108			545	0.005 LB/LB DESIGN LANDING WT (MAX)		
MAIN LANDING GEAR	2	431			308	0.02 LB/LB DESIGN LANDING WT (MAX)		
LANDING GEAR SUPT/INSTL		54			355		10 % OF SYSTEM	
SEPARATION			130					
LAUNCH ESCAPE MOTOR SEPARATION	2	40			180	L=20 FT @ 2.0 LB/FT		
LAUNCH VEHICLE SEP BOLTS	6	90			180			

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Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 5 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PROPULSION - REACTION CONTROL				**996**	**479**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
THRUSTER MODULES - FORWARD			116		505			
THRUSTERS - RCS	10	83						
THRUSTERS - COLD GAS	6	22				MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTER MODULE SUPPORT	4	11				10 % OF SYS		
THRUSTER MODULES - AFT			97		190			
THRUSTERS - RCS	8	66						
THRUSTERS - COLD GAS	6	22				MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTER MODULE SUPPORT	4	9				10 % OF SYS		
PRESSURIZATION SYSTEM			23		505			
GN2 BOTTLE(S) - RCS	0	0				INCL IN COLD GAS SYSTEM		
REGULATORS	0	0				FAIRCHILD		
FILL & DRAIN DISCONNECTS	1	1				PYRONETICS		
MANIFOLD/PLUMBING		10				BOEING		
TANK VENT / RELIEF		9						
PRESS SYS SUPPORT		3				15 % OF SYS		
PROPELLANT SUPPLY - RCS			200		530			
TANKAGE - H2O2	2	60				31.0-IN DIAMETER SPHERICAL	NEW	
TANKAGE - RP	2	22				16.5-IN DIAMETER SPHERICAL	NEW	
VALVES	9	35				CONSOLIDATED CONTROLS		
MANIFOLD/PLUMBING	1	40				BOEING 304L SS		
TANK FILL, VENT & DRAIN	2	25						
PROPELLANT SUPPLY SUPPORT		18				10 % OF SYS		
PROPELLANT SUPPLY - PROX-OPS (fixed)			560		505			
N2 BOTTLE(S) - OMS, RCS, COLD GAS	4	350				15-IN ID X 74-IN LONG	KEVLAR O/W Ti	
VALVES	16	82				CONSOLIDATED CONTROLS		
FLIGHT DISCONNECT	1	1				PYRONETICS		
FILL / DRAIN DISCONNECT	4	4				PYRONETICS		
MANIFOLD/PLUMBING		42				BOEING 304L SS		
TANK VENT / RELIEF		14						
TANK SEPARATION	4	16				EXPLOSIVE BOLTS		
COLD GAS SUPPLY SUPPORT		51				10 % OF SYS		

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Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 6 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PROPULSION - ORBIT MANEUVER				**563**	**236**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
THRUSTER MODULES			165					
ENGINES	3	150			185			
ENGINE MOUNT	3	15			195			
PRESSURIZATION SYSTEM			62					
GN2 BOTTLES - OMS	0	0			505	INCL IN COLD GAS SYSTEM		
GAS VALVES	4	18			505	MOOG		
REGULATORS	2	9			505	FAIRCHILD		
FILL & DRAIN DISCONNECTS	2	2			505	PYRONETICS		
MANIFOLD/PLUMBING		10			365	BOEING 304L SS		
BOTTLE VENT / RELIEF		17			505	FAIRCHILD		
PRESS SYSTEM SUPPORT		6			505	15 % OF OMS		
PROPELLANT SUPPLY - OMS			336					
LO2 SYSTEM - TANK	2	102			230	44.0 in ID TANK, WITH INSULATION	ALUMINUM	
LO2 SYSTEM - VALVES	4	16			230			
LO2 SYSTEM - MANIFOLD	1	20			200	8 FT @ 2.5 LB/FT	ALUMINUM	
LO2 SYSTEM - FILL, DRAIN, VENT	1	24			200			
LO2 SYSTEM - SUPPORT, INSTL		24			200	15 % OF OMS		
RP SYSTEM - TANK	2	70			220	35.0 in ID TANK, WITH INSULATION	ALUMINUM	
RP SYSTEM - VALVES	4	16			220			
RP SYSTEM - MANIFOLD	1	20			195	8 FT @ 2.5 LB/FT	ALUMINUM	
RP SYSTEM - FILL, DRAIN, VENT	1	24			195			
RP SYSTEM - SUPPORT, INSTL		20			195	15 % OF OMS		
PROPULS - LAUNCH ESCAPE SYSTEM				**2211**	**156**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
LAUNCH ESC MOTOR / TURBOPUMP (JETT)			1410					
TURBOPUMP ASSEMBLY	2	1140			155	ESTIMATE		
ENGINE	1	250			130	ESTIMATE		
ENGINE / TURBOPUMP MOUNT	1	20			160			
TURBOPUMP GAS GENERATOR (JETT)			360					
GAS GENERATOR	1	200			155	ESTIMATE		
GAS GENERATOR TANKAGE (WET)	1	160			155	ESTIMATE		
PROPELLANT SUPPLY (JETT)			71					
LO2 SYSTEM - DISCONNECT	1	12			190	DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	29			170	DIA = 5.0 IN, L=5 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			190	DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	18			170	DIA = 5.0 IN, L=5 FT @ 3.5 LB/FT	ALUMINUM	
PROPELLANT SUPPLY (FIXED)			169					
LO2 SYSTEM - DISCONNECT	1	12			190	DIA=5.0 IN		
LO2 SYSTEM - VALVE	2	40			198	DIA=5.0 IN		
LO2 SYSTEM - MANIFOLD	1	40			198	DIA = 5.0 IN, L=7 FT @ 5.7 LB/FT	ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			190	DIA=5.0 IN		
RP SYSTEM - VALVE	2	40			198	DIA=5.0 IN		
RP SYSTEM - MANIFOLD	1	25			198	DIA = 5.0 IN, L=7 FT @ 3.5 LB/FT	ALUMINUM	
EQUIPMENT SUPPORT/INSTL			201		155	10 % OF EQUIPMENT		

Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 7 of 13)

GROUP WEIGHT STATEMENT Winged PLS Concept #4 (10 Personnel, Tile TPS)	NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
POWER - ELECTRICAL				2205	487		15
POWER SUPPLY			1348			FUEL CELL SYSTEM - 6 KW NOM, 9 KW PEAK TOTAL	
FUEL CELLS	2	361			565	Reduced Shuttle Cells - 2 of 3 to supply sustained power	
BATTERIES	6	432			565	Contingency only - 48 kw-hr LI-SOCL2	
O2 TANKAGE (EPS & ECLSS)	2	110			524	21.0 in ID VACUUM -JACKETED TANK	
H2 TANKAGE	2	116			533	26.0 in ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	4	12			530		
REACTANT RELIEF, VENT PLUMBING	4	64			530		
REACTANT SUPPLY PLUMBING	4	20			565		
REACTANT SUPPLY VALVES, DISC	4	12			550		
COOLANT PLUMBING		45			500	INCL. 30 LB FLUIDS	
WASTE WATER TANK		0				INCL IN WATER MANAGEMENT	
POWER SUPPLY SUPT/INSTL		176			554	15 % OF SYS	
POWER DIST EQUIP			169				
POWER DISTRIBUTION PANELS	3	99			480		
10VDC POWER SUPPLY	3	1			480		
EXTERIOR LIGHTS		15			415	ESTIMATE	
INTERIOR LIGHTS		20			365	ESTIMATE	
POWER DISTRIBUTION SUPT/INSTL		34			450	25 % OF SYS	
WIRING			688			ESTIMATE	
POWER DISTR. WIRE HARNESSES		400			365		
INSTRUMENTATION WIRING		100			365		
ELECTRICAL CONNECTORS		50			365	BULKHEAD FEEDTHRU PLATES	
HARNESS SUPT/INSTL		138			365	25 % OF SYS	
SURFACE CONTROLS				363	208		15
ELEVON ACTUATION			121			DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110			223		
ACTUATOR SUPT/INSTL		11			223	10 % OF SYS	
RUDDER ACTUATION			121			DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110			180		
ACTUATOR SUPT/INSTL		11			180	10 % OF SYS	
BODY FLAP ACTUATION			121			DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110			220		
ACTUATOR SUPT/INSTL		11			220	10 % OF SYS	

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Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 8 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
AVIONICS				**1736**	**428**		**15**
GUIDANCE, NAVIGATION AND CONTROL			319		465		
FAULT-TOLERANT NAVIGATOR	1	50					
GPS RECEIVER	2	12					
GPS ANTENNAS	2	10					
HORIZON SCANNER	2	12					
RADAR ALTIMETER	2	10					
ELEVON DRIVER	1	45					
RUDDER DRIVER	1	45					
BODY FLAP DRIVER	1	45					
RCS/ OMS VALVE DRIVER	2	90					
RENDEVOUS AND DOCK			133		320		
RENDEVOUS RADAR	1	30					
RADAR SIGNAL PROCESSOR	1	70					
ANTENNA	1	8					
ANTENNA MAST, DEPLOYMENT MECHS	1	25					
VEHICLE HEALTH MONITORING			75			SENSORS INCL IN INSTRUMENTATION COUNT	
MASS MEMORY	3	75			465		
COMMUNICATIONS AND TRACKING			238		465		
CENTRAL DATA FORMATTER	1	27					
TRANSPONDER	1	16					
POWER AMP	1	18					
DIPLEXER, RF SWITCH	1	3					
AUDIO	1	40					
UHF TRANSCEIVER	1	20					
ANTENNAS	3	24					
SEARCH AND RESCUE RADIO	1	40				ESTIMATED	
SIGNAL CABLING		50				ESTIMATED	
CONTROLS AND DISPLAYS			185		460		
RECONFIG DISPLAYS / CONTROL UNITS	5	50					
ELECTRONIC INTERFACES	3	75					
RECONFIG. PUSH-BUTTON PANEL	3	30					
RMS WORKSTATION	0	0				ESTIMATE FOR SERVICING MISSION	
HAND CONTROLLERS	2	30					
INSTRUMENTATION			83				
SENSOR INTERFACE UNIT (SIU)	60	30			365		
NETWORK INTERFACE UNIT (NIU)	2	3			465		
SENSORS, INSTRUMENTATION	700	50			365		
DATA HANDLING			463		465		
FAULT TOLERANT PROCESSOR	3	99					
MASS MEMORY	3	75				ESTIMATED	
DATA BUS COUPLERS	60	30					
MDM	7	259					
STRUCTURES/MECHS CONTROLS			82				
CHUTE, LANDING GEAR CONTROLLER	1	61			200		
LASER FIRING UNIT	2	20			255		
LASER INITIATORS	5	1			255		
AVIONICS SUPT/INSTL			158		365	10 % OF AVIONICS	

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Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 9 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			XCG	REMARKS	WG%
ENVIRONMENTAL CONTROL				**1471**	**355**		**15**
CABIN AND PERSONNEL SYSTEM			475				
O2 TANKAGE - CRYO STORAGE	0	0			0	INCL IN FUEL CELL REACTANT STORAGE	
O2 TANKAGE - (GAS FOR REPRESS)	1	25			435	Kevlar / Inconel	
N2 TANKAGE - (GAS FOR REPRESS)	2	96			435	Kevlar / Titanium	
PRESS PLUMBING		12			435		
CABIN PRESS & COMPOSITION CNTRLS		65			455	VALVES, VENT RELIEF VALVES, ETC	
CO2 REMOVAL - 2-BED LIOH		11			365	LIOH CANISTER UNIT - 2 CANISTER UNIT	
LIOH CANISTER STORAGE - NOMINAL		43			410	(7.0 LB/2-PERSON-DAY)	
LIOH CANISTER STORAGE - CONTING.		70			410	48-HR @(7.0 LB/2-PERSON-DAY)	
TEMP AND HUMIDITY CONTROL		127			300	FANS/SEPARATORS, HEAT EXCHANGER, ETC	
TRACE CONTAMINANT CONTROL		7			300	CANISTER FOR IMPURITY REMOVAL	
DUCTING, MISC		20			365	FANS INCLUDED IN TEMPERATURE CONTROL	
EQUIPMENT COOLING			209		465		
EQUIPMENT COLD PLATES		120				S= 60 SF @ 2.0 PSF	
AVIONICS COOLING ASSY		28				INCL HX, FANS, DUCTING	
IMU HEAT EXCHANGER ASSY	1	31					
PLUMBING		20					
DUCTING, MISC		10				FANS INCLUDED IN TEMPERATURE CONTROL	
HEAT TRANSFER WATER LOOP			161		365		
HEAT EXCHANGER - POTABLE WATER	1	17				BASED ON SHUTTLE	
PRIMARY, SECONDARY WATER PUMPS		78					
PLUMBING		30					
COOLANT IN LOOP - WATER		36					
HEAT TRANSFER FREON LOOP			270				
HEAT EXCHANGER - WATER-FREON	1	50			255	BASED ON SHUTTLE	
HEAT EXCHANGER - GSE	1	50			195	BASED ON SHUTTLE	
HEAT EXCHANGER - FUEL CELL	1	50			565	BASED ON SHUTTLE	
FREON PUMP PACKAGE	2	90			205		
COOLANT IN LOOP - FREON		30			205		
HEAT REJECTION			222		255		
AMMONIA BOILER ASSEMBLY		45				INCL AMMONIA TANK, HEAT EXCHNGR, VENT, VALVES	
COOLANT TANKAGE - WATER		14					
FLASH EVAPORATOR - WATER		58				FROM SHUTTLE	
TOPPING DUCT ASSEMBLY		78					
HIGH LOAD DUCT ASSEMBLY		27					
RADIATOR PANELS			0			INCL ON AFT ADAPTER	
ECLSS SUPT/INSTL			134		365	10 % OF ECLSS	

Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 10 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			XCG	REMARKS	WG%
PERSONNELPROVISIONS				1486	368		15
FOOD MANAGEMENT			117				
GALLEY		0			365	GALLEY UNIT, WITH WATER DISPENSER	
FOOD STORAGE UNITS		117			365		
WATER MANAGEMENT			63		465		
WATER STORAGE TANK	2	28				FOR POTABLE WATER STORAGE	
HANDWASH - WET WIPES		2					
WATER DISPENSER		23				WATER DISPENSER ONLY	
PLUMBING, VALVES, ETC		10					
WASTE MANAGEMENT			58		280		
WASTE WATER TANK	2	28					
COMMODE SYSTEM		15				installation scar only for crew rotation	
EMERGENCY WASTE COLLECTION		15				SHUTTLE TYPE	
FIRE DETECTION / SUPPRESSION			13		465		
SMOKE DETECTORS		7					
FIRE SUPPRESSION TANK		6				INCLUDES SUPPRESSANT	
FURNISHINGS AND EQUIPMENT			1100				
SEATS, PERSONNEL RESTRAINTS	2	200			290	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			330	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			370	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			410	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			440	INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SLEEP STATIONS		0			350	NOT REQUIRED FOR TRANSFER	
INCIDENTAL EQUIPMENT	10	100			350	STORAGE FOR ASTRONAUT PERSONAL EFFECTS	
SUPPORT/INSTALLATION			135		365	10 % OF ECLSS	
CREW MOD DRY, EXCL GROWTH				25138	324		14.1
WEIGHT GROWTH MARGIN				3771	324	14 % OF DRY WT	
CREW MODULE DRY WEIGHT				28909	324		

BOEING

Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 11 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS	WG%
NON- CARGO ITEMS				**4301**	**373**		
CREW, WITH EQUIPMENT			3000				
FLIGHT CREW / personal effects	2	600			290	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			330	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			370	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			410	90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			440	90TH PERCENTILE + 107 lb ea.	
TOOLS, MISCELLANEOUS	0	0			330		
EVA SUITS, WITH EXPENDABLES	0	0			330		
PROPELLANT RESIDUALS			421				
OMS RESIDUALS - IN TANKS		73			225	0.3 FT3 PER TANK	
OMS RESIDUALS - IN LINES, ENGINES		132			225	8 FT EA, 5.0 IN DIA.	
OMS PRESSURANTS		97			505	0.0251 LB/LB PROPELLANT NITROGEN	
RCS RESIDUAL BI-PROP		46			500	RESIDUAL IN TANKS AND LINES	
RCS N2 PRESSURANT		18			500		
COLD GAS RESIDUALS		56			505		
PROPELLANT RESERVES			880				
OMS RESERVES		350			225	10% OF NOMINAL	
RCS RESERVES - BIPROP		269			500	20% OF NOMINAL PROPELLANT	
RCS RESERVES - COLD GAS		261			505	20% OF NOMINAL PROPELLANT	
PAYLOAD / CARGO				**0**		**NO CARGO CAPABILITY**	
CREW MODULE INERT WEIGHT				**33211**	**330**		

ITEM	QTY	VALUE			XCG	REMARKS	WG%
NON- PROPELLANT				**855**	**439**		
IN-FLIGHT LOSSES			334			(CR- 264 KW-HR; SS- 840 KW-HR)	
FUEL CELL NOMINAL O2		238			524	0.71 LB/ KW -HR	
FUEL CELL NOMINAL H2		30			533	0.09 LB/ KW-HR	
FUEL CELL O2 RESERVES		48			524	20% NOMINAL	
FUEL CELL H2 RESERVES		6			533	20% NOMINAL	
FUEL CELL RESIDUAL REACTANT		13			528	ESTIMATE	
LIFE SUPPORT CONSUMABLES			521				
O2 - CRYO STORAGE		34			524	METABOLIC CONSUMPT. (2 LB/M-DAY) +20%	
O2 - GAS FOR REPRESSURIZATION		15			435	1 repress contingency + leak (0.38 LB/DAY)	
O2 - CABIN PRESSURIZATION		14			365		
N2 - GAS FOR REPRESS, LOSSES		67			435	1 repress contingency + leak (1.26 LB/DAY)	
N2 - CABIN PRESSURIZATION		63			365		
FOOD - nominal		56			365	4 LB/M-DAY	
FOOD - contingency		80			365	4 LB/M-DAY -- 48 hr contingency	
POTABLE WATER - nominal		0			465	4 LB/M-DAY supplied by fuel cells	
POTABLE WATER - contingency		92			465	4 LB/M-DAY --48 HR CONTINGENCY + resid	
EQUIP COOLING FLUIDS - AMMONIA		45			255	WATER FOR LAUNCH & REENTRY COOLING ONLY + 20 %	
EQUIP COOLING FLUIDS - WATER		55			255	WATER FOR LAUNCH & REENTRY COOLING ONLY + 20 %	

Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 12 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			XCG	REMARKS		WG%
PROPELLANT - NOMINAL				**4177**	**270**			
RCS NOM PROPELLANT - BIPROP			495		500			
RCS NOM PROPELLANT - COLD GAS			186		505			
OMS NOMINAL PROPELLANT			3496		225	DELTA V AS SHOWN		
GROSS WEIGHT				**38243**	**326**			
ADAPTER / RADIATOR MODULE				**2522**	**105**			
STRUCTURE			989		105			
AFT ADAPTER INTERFACE RING	1	158				L=43 FT, A=3.0 IN2	ALUMINUM	
CREW MODULE INTERFACE RING	1	92				L=30.6 FT, A=2.5 IN2	ALUMINUM	
MINOR FRAMES	2	134				L=37.3 FT, A=1.5 IN2	ALUMINUM	
LONGERONS	6	257				L=11.9 FT, A=3.0 IN2	ALUMINUM	
INTERMEDIATE STRUTS / FTGS	18	248				L ave=7.1 FT, A=1.0 IN2 +1.0 LB FTGS	ALUMINUM	
RADIATOR PANEL LINKAGE & HINGES	2	40						
LAUNCH / CREW MOD UMBIL PLATES	2	60						
THERMAL PROTECTION			71		105	S= 1034 SF, @ 0.0685 PSF	FOSR	
POWER DISTRIBUTION			188		105			
WIRING, INCL GROUND UMBILICALS		150						
EQUIPMENT SUPPORT/INSTL		38					25 % OF WIRING	
ECLSS RADIATOR PANELS			795		105		ALUMINUM	
COOLANT IN PANELS - FREON		30						
FIXED PANELS	2	304				A=134 sf ea @ 1.14 psf	ALUMINUM	
DEPLOYED PANELS	2	461				A=134 sf ea (134 sf ea side) @ 1.72 psf	ALUMINUM	
OTHER - AUXILIARY SYSTEMS			150		105			
LAUNCH VEHICLE SEPARATION	6	90				EXPLOSIVE BOLT SEPARATION		
CREW MODULE SEPARATION	6	60				EXPLOSIVE BOLT SEPARATION		
WEIGHT GROWTH MARGIN			329		105		15 % OF HARDWARE	
GROSS WEIGHT				**40765**	**312**			
LAUNCH VEHICLE ADAPTER				**1956**	**-60**			
STRUCTURE			1363		-60	S= 545 SF @ 2.5 PSF	ALUM SKIN/STR	
PROTECTION - THERMAL			0		-60			
POWER - WIRE HARNESS			188		-60	L= 8 FT, INCL CONNECTORS, ETC		
OTHER - CREW MOD SEPARATION SYS	6		150		-60	SEP BOLTS		
WEIGHT GROWTH MARGIN			255		-60		15 % OF HARDWARE	
BALLAST				**0**	**0**			
FWD NOSE BALLAST			0		550			
TOTAL LAUNCH WEIGHT				**42721**	**295**			

Table 21.3-11 Detailed Mass Properties for Configuration IV (10 Persons) (Page 13 of 13)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE	XCG	REMARKS	WG%
SEQUENCED MASS DATA					
TOTAL WEIGHT		**42721**	**295**		
SEPARATE FROM LAUNCH VEH ADAPTER		-1956	-60		
ON-PAD ABORT WEIGHT		**40765**	**312**		
JETTISON LAUNCH ESCAPE ENG, FEED		-2543	156		
JETTISON LAUNCH ESCAPE THRUST STR		-178	177		
ON-ORBIT WEIGHT		**38045**	**323**		
DELETE CONSUMABLES TO REENTRY		-69	383		
DELETE POWER FLUIDS TO REENTRY		-263	525		
DELETE NOMINAL RCS ON-ORBIT PROP		-357	500		
DELETE PROX OPS COLD GAS		-186	505		
DELETE OMS ON-ORBIT PROP		-3496	225		
SEPARATE SERVICE MODULE		0	0		
SEPARATE RADIATOR MODULE		-2522	105		
BEGIN REENTRY WEIGHT		**31151**	**347**		
DELETE CONSUMABLES		-13	383		
DELETE REENTRY POWER FLUIDS		-5	525		
DELETE NOMINAL RCS REENTRY PROP		-138	500		
LANDING WEIGHT		**30996**	**346**		

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 1 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE		REMARKS	WG%
PERSONNEL		6			
CREW	2				
PASSENGERS	4				
MISSION DURATION (DAYS)		3.0			
ECLSS					
CLOSURE LEVEL		OPEN			
PRESSURIZED VOLUME -CABIN (FT3)		619.0		60% VOLUME, 71% AREA RATIO, 78% MASS RATIO	
PRESSURIZED VOLUME -AIRLOCK (FT3)		0.0			
PRESS/REPRESS EVENTS		2.0			
CABIN LEAKAGE (%VOLUME/DAY)		2.0			
PROPULSION	Delta V	Isp,sec			
RCS - H2O2/RP	146	310			
COLD GAS - N2	10	60			
OMS - LO2/RP	989	315			
LES - Expend Liquid Pusher	606	310			
ON-PAD ABORT WEIGHT		33619			
ON-ORBIT WEIGHT		30898			
LANDING WEIGHT		24900			
DESIGN LANDING WEIGHT		25000			
STRUCTURE - WING GROUP		942			15
WING BASIC STRUCTURE		587			
WING SECONDARY STRUCTURE		233			
CONTROL SURFACES		122			
STRUCTURE - TAIL GROUP		252			15
TIP FIN BASIC STRUCTURE		153			
CONTROL SURFACES		99			

BOEING

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 2 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY		VALUE		REMARKS	WG%
STRUCTURE - BODY GROUP				5164		15
FWD FUSELAGE BASIC STRUCTURE			471		(X.484- X.580) ALUM SKIN / STR	
MID FUSELAGE BASIC STRUCTURE			1049		(X.245- X.484) ALUM SKIN / STR	
AFT FUSELAGE BASIC STRUCTURE			557		(X.174- X.245) ALUM SKIN / STR	
THRUST STRUCTURE - OMS (FIXED)			242			
THRUST STRUTS	4	58			L=5 FT, A=2.0 IN2 +20% ALUMINUM	
THRUST STR STABILIZING STRUTS	TBD	29				
ENG INTERFACE FTGS	3	9			ESTIMATE	
TANK SUPPORT STRUTS	8	66			L= 72 IN, A=1.0 IN2 + 1 LB FTGS EA ALUMINUM	
TANK SWAY STRUTS	16	72			L=40 IN, A=1.0 IN2 + 1 LB FTG EA ALUMINUM	
PRESS TANK SUPT FLANGES	8	8			ESTIMATE ALUMINUM	
THRUST STRUCT. - LAUNCH ESCAPE (JETT)			155			
ENGINE THRUST STRUTS	3	87			L=15 FT, A=4.0 IN2 + 20% ALUMINUM	
STABILIZING STRUTS, FTGS, ETC	TBD	44			ESTIMATE	
THRUST STRUCT SEPARATION BOLTS	3	24				
FWD FUSELAGE SECONDARY STRUCTURE			204			
MID FUSELAGE SECONDARY STRUCT			302			
WINDOW, THERMAL	6	43			S,ave=0.8 SF EA @ 9.0 PSF	
WINDOW, RETAINER	6	15				
DOCKING HATCH COVER	1	150			S= 50 SF @ 3.0 PSF	
DOCKING COVER HINGES, MECHANISM	1	50			ESTIMATE	
RMS GRAPPLE FITTING	2	44				
AFT FUSELAGE SECONDARY STRUCT			259			
SERVICE MODULE UMBILICAL PLATE	1	20				
LAUNCH/PROP MODULE UMBIL PLATE	1	20				
BODY FLAP	1	176			RCC/ INSTL	
BODY FLAP CLOSEOUT/HINGE SUPT	1	43				
CREW MODULE BASIC STRUCTURE			917		ALUMINUM SKIN / STRINGER	
CREW MODULE SECONDARY STRUCTURE			1008		ALUMINUM SKIN / STRINGER	
INTERNAL EQUIPMENT BAY	1	100			S= 67 SF @ 1.5 PSF	
EQUIPMENT SUPPORT RACKS	2	150			S=100 SF @ 1.5 PSF	
WINDOWS	6	130			S= 0.8 SF EA @ 27 PSF	
WINDOWS, RETAINER	6	65				
DOCKING ADAPTER MECHANISM	1	340				
AIRLOCK INTERFACE RING	0	0			L= 13.0 FT, A= 2.5 IN2 + 20% ALUMINUM	
TOP HATCH, STRUCTURE	1	58			36-IN DIA	
TOP HATCH, MECHANISM	1	32				
SIDE HATCH, STRUCTURE	1	72			40-IN DIA, SHUTTLE-TYPE	
SIDE HATCH, WINDOW & RETAINER	1	20				
SIDE HATCH, MECHANISM	1	41				
PROTECTION				2617		15
EXTERNAL TPS - WING			948			
EXTERNAL TPS - TIP FINS			229			
EXTERNAL TPS - BODY			1183			
INTERNAL INSULATION / TCS			187			
PURGE AND VENT SYSTEM			51		SCALED FROM SHUTTLE	
DUCTING		21				
VALVES		20				
SUPPORT, INSTALLATION		10				
WINDOW / HATCH CONDITIONING			19		SCALED FROM SHUTTLE	
PLUMBING		7				
DESSICANT, VALVES, DISCONNECTS		8				
SUPPORT, INSTALLATION		4				

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 3 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS		WG%
RECOVERY & AUXILIARY SYSTEMS				2033			15
DROGUE CHUTE SYSTEM			1441				
DROGUE CHUTES	1	330			FOR ABORT AND BRAKED LANDING		
BACKUP DROGUE	1	330					
ABORT MAIN CHUTE	1	650					
PARACHUTE SUPT/INSTL		131				10 % OF SYSTEM	
LANDING SYSTEM			462				
NOSE LANDING GEAR	1	84			0.005 LB/LB DESIGN LANDING WT (MAX)		
MAIN LANDING GEAR	2	336			0.02 LB/LB DESIGN LANDING WT (MAX)		
LANDING GEAR SUPT/INSTL		42				10 % OF SYSTEM	
SEPARATION			130				
LAUNCH ESCAPE MOTOR SEPARATION	2	40			L=20 FT @ 2.0 LB/FT		
LAUNCH VEHICLE SEP BOLTS	6	90					

BOEING

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 4 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	QTY	CREW ROTATION VALUE			REMARKS		WG%
PROPULSION - REACTION CONTROL				**882**	**H2O2 / RP SYSTEM; EXTERNAL PRESS**		**15**
THRUSTER MODULES - FORWARD			116				
THRUSTERS - RCS	10	83			MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTERS - COLD GAS	6	22					
THRUSTER MODULE SUPPORT	4	11			10 % OF SYS		
THRUSTER MODULES - AFT			97				
THRUSTERS - RCS	8	66			MOOG 5264 - 30 LBF N2 THRUSTERS		
THRUSTERS - COLD GAS	6	22					
THRUSTER MODULE SUPPORT	4	9			10 % OF SYS		
PRESSURIZATION SYSTEM			21				
GN2 BOTTLE(S) - RCS	0	0			INCL IN COLD GAS SYSTEM		
REGULATORS	0	0			FAIRCHILD		
FILL & DRAIN DISCONNECTS	1	1			PYRONETICS		
MANIFOLD/PLUMBING		8			BOEING		
TANK VENT / RELIEF		9					
PRESS SYS SUPPORT		3			15 % OF SYS		
PROPELLANT SUPPLY - RCS			174				
TANKAGE - H2O2	2	48			31.0-IN DIAMETER SPHERICAL	NEW	
TANKAGE - RP	2	18			16.5-IN DIAMETER SPHERICAL	NEW	
VALVES	9	35			CONSOLIDATED CONTROLS		
MANIFOLD/PLUMBING	1	32			BOEING 304L SS		
TANK FILL, VENT & DRAIN	2	25					
PROPELLANT SUPPLY SUPPORT		16			10 % OF SYS		
PROPELLANT SUPPLY - PROX-OPS (fixed)			474				
N2 BOTTLE(S) - OMS, RCS, COLD GAS	4	280			15-IN ID X 74-IN LONG	KEVLAR O/W TI	
VALVES	16	82			CONSOLIDATED CONTROLS		
FLIGHT DISCONNECT	1	1			PYRONETICS		
FILL / DRAIN DISCONNECT	4	4			PYRONETICS		
MANIFOLD/PLUMBING		34			BOEING 304L SS		
TANK VENT / RELIEF		14					
TANK SEPARATION	4	16			EXPLOSIVE BOLTS		
COLD GAS SUPPLY SUPPORT		43			10 % OF SYS		

BOEING

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 5 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
PROPULSION - ORBIT MANEUVER				513	**H2O2 / RP SYSTEM; EXTERNAL PRESS**	15
THRUSTER MODULES			165			
ENGINES	3	150				
ENGINE MOUNT	3	15				
PRESSURIZATION SYSTEM			60			
GN2 BOTTLES - OMS	0	0			INCL IN COLD GAS SYSTEM	
GAS VALVES	4	18			MOOG	
REGULATORS	2	9			FAIRCHILD	
FILL & DRAIN DISCONNECTS	2	2			PYRONETICS	
MANIFOLD/PLUMBING		8			BOEING 304L SS	
BOTTLE VENT / RELIEF		17			FAIRCHILD	
PRESS SYSTEM SUPPORT		6			15 % OF OMS	
PROPELLANT SUPPLY - OMS			288			
LO2 SYSTEM - TANK	2	82			ALUMINUM	
LO2 SYSTEM - VALVES	4	16				
LO2 SYSTEM - MANIFOLD	1	16			8 FT @ 2.5 LB/FT ALUMINUM	
LO2 SYSTEM - FILL, DRAIN, VENT	1	24				
LO2 SYSTEM - SUPPORT, INSTL		21			15 % OF OMS	
RP SYSTEM - TANK	2	56			ALUMINUM	
RP SYSTEM - VALVES	4	16				
RP SYSTEM - MANIFOLD	1	16			8 FT @ 2.5 LB/FT ALUMINUM	
RP SYSTEM - FILL, DRAIN, VENT	1	24				
RP SYSTEM - SUPPORT, INSTL		17			15 % OF OMS	
PROPULS - LAUNCH ESCAPE SYSTEM				2211	**H2O2 / RP SYSTEM; EXTERNAL PRESS**	15
LAUNCH ESC MOTOR / TURBOPUMP (JETT)			1410			
TURBOPUMP ASSEMBLY	2	1140			ESTIMATE	
ENGINE	1	250			ESTIMATE	
ENGINE / TURBOPUMP MOUNT	1	20				
TURBOPUMP GAS GENERATOR (JETT)			360			
GAS GENERATOR	1	200			ESTIMATE	
GAS GENERATOR TANKAGE (WET)	1	160			ESTIMATE	
PROPELLANT SUPPLY (JETT)			71			
LO2 SYSTEM - DISCONNECT	1	12			DIA=5.0 IN	
LO2 SYSTEM - MANIFOLD	1	29			DIA = 5.0 IN, L=5 FT @ 5.7 LB/FT ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			DIA=5.0 IN	
RP SYSTEM - MANIFOLD	1	18			DIA = 5.0 IN, L=5 FT @ 3.5 LB/FT ALUMINUM	
PROPELLANT SUPPLY (FIXED)			169			
LO2 SYSTEM - DISCONNECT	1	12			DIA=5.0 IN	
LO2 SYSTEM - VALVE	2	40			DIA=5.0 IN	
LO2 SYSTEM - MANIFOLD	1	40			DIA = 5.0 IN, L=7 FT @ 5.7 LB/FT ALUMINUM	
RP SYSTEM - DISCONNECT	1	12			DIA=5.0 IN	
RP SYSTEM - VALVE	2	40			DIA=5.0 IN	
RP SYSTEM - MANIFOLD	1	25			DIA = 5.0 IN, L=7 FT @ 3.5 LB/FT ALUMINUM	
EQUIPMENT SUPPORT/INSTL			201		10 % OF EQUIPMENT	

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 6 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
POWER - ELECTRICAL				2142		15
POWER SUPPLY			1348		FUEL CELL SYSTEM - 6 KW NOM, 9 KW PEAK TOTAL	
FUEL CELLS	2	361			Reduced Shuttle Cells - 2 of 3 to supply sustained power	
BATTERIES	6	432			Contingency only - 48 kw-hr LI-SOCL2	
O2 TANKAGE (EPS & ECLSS)	2	110			21.0 In ID VACUUM -JACKETED TANK	
H2 TANKAGE	2	116			26.0 In ID VACUUM -JACKETED TANK	
REACTANT FILL & DRAIN PLUMBING	4	12				
REACTANT RELIEF, VENT PLUMBING	4	64				
REACTANT SUPPLY PLUMBING	4	20				
REACTANT SUPPLY VALVES, DISC	4	12				
COOLANT PLUMBING		45			INCL. 30 LB FLUIDS	
WASTE WATER TANK		0			INCL IN WATER MANAGEMENT	
POWER SUPPLY SUPT/INSTL		176			15 % OF SYS	
POWER DIST EQUIP			169			
POWER DISTRIBUTION PANELS	3	99				
10VDC POWER SUPPLY	3	1				
EXTERIOR LIGHTS		15			ESTIMATE	
INTERIOR LIGHTS		20			ESTIMATE	
POWER DISTRIBUTION SUPT/INSTL		34			25 % OF SYS	
WIRING			625		ESTIMATE	
POWER DISTR. WIRE HARNESSES		350				
INSTRUMENTATION WIRING		100				
ELECTRICAL CONNECTORS		50			BULKHEAD FEEDTHRU PLATES	
HARNESS SUPT/INSTL		125			25 % OF SYS	
SURFACE CONTROLS				363		15
ELEVON ACTUATION			121		DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110				
ACTUATOR SUPT/INSTL		11			10 % OF SYS	
RUDDER ACTUATION			121		DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110				
ACTUATOR SUPT/INSTL		11			10 % OF SYS	
BODY FLAP ACTUATION			121		DUAL REDUNDANT ELECTROMECHANICAL ACTUATOR	
ACTUATORS	2	110				
ACTUATOR SUPT/INSTL		11			10 % OF SYS	

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 7 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
AVIONICS				1736		15
GUIDANCE, NAVIGATION AND CONTROL			319			
FAULT-TOLERANT NAVIGATOR	1	50				
GPS RECEIVER	2	12				
GPS ANTENNAS	2	10				
HORIZON SCANNER	2	12				
RADAR ALTIMETER	2	10				
ELEVON DRIVER	1	45				
RUDDER DRIVER	1	45				
BODY FLAP DRIVER	1	45				
RCS/ OMS VALVE DRIVER	2	90				
RENDEVOUS AND DOCK			133			
RENDEVOUS RADAR	1	30				
RADAR SIGNAL PROCESSOR	1	70				
ANTENNA	1	8				
ANTENNA MAST, DEPLOYMENT MECHS	1	25				
VEHICLE HEALTH MONITORING			75		SENSORS INCL IN INSTRUMENTATION COUNT	
MASS MEMORY	3	75				
COMMUNICATIONS AND TRACKING			238			
CENTRAL DATA FORMATTER	1	27				
TRANSPONDER	1	16				
POWER AMP	1	18				
DIPLEXER, RF SWITCH	1	3				
AUDIO	1	40				
UHF TRANSCEIVER	1	20				
ANTENNAS	3	24				
SEARCH AND RESCUE RADIO	1	40			ESTIMATED	
SIGNAL CABLING		50			ESTIMATED	
CONTROLS AND DISPLAYS			185			
RECONFIG DISPLAYS / CONTROL UNITS	5	50				
ELECTRONIC INTERFACES	3	75				
RECONFIG. PUSH-BUTTON PANEL	3	30				
RMS WORKSTATION	0	0			ESTIMATE FOR SERVICING MISSION	
HAND CONTROLLERS	2	30				
INSTRUMENTATION			83			
SENSOR INTERFACE UNIT (SIU)	60	30				
NETWORK INTERFACE UNIT (NIU)	2	3				
SENSORS, INSTRUMENTATION	700	50				
DATA HANDLING			463			
FAULT TOLERANT PROCESSOR	3	99				
MASS MEMORY	3	75				
DATA BUS COUPLERS	60	30			ESTIMATED	
MDM	7	259				
STRUCTURES/MECHS CONTROLS			82			
CHUTE, LANDING GEAR CONTROLLER	1	61				
LASER FIRING UNIT	2	20				
LASER INITIATORS	5	1				
AVIONICS SUPT/INSTL			158		10 % OF AVIONICS	

BOEING

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 8 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
ENVIRONMENTAL CONTROL				**1311**		**15**
CABIN AND PERSONNEL SYSTEM			350			
O2 TANKAGE - CRYO STORAGE	0	0			INCL IN FUEL CELL REACTANT STORAGE	
O2 TANKAGE - (GAS FOR REPRESS)	1	15			Kevlar / Inconel	
N2 TANKAGE - (GAS FOR REPRESS)	2	58			Kevlar / Titanium	
PRESS PLUMBING		12				
CABIN PRESS & COMPOSITION CNTRLS		52			VALVES, VENT RELIEF VALVES, ETC	
CO2 REMOVAL - 2-BED LiOH		11			LIOH CANISTER UNIT - 2 CANISTER UNIT	
LiOH CANISTER STORAGE - NOMINAL		31			(7.0 LB/2-PERSON-DAY)	
LiOH CANISTER STORAGE - CONTING.		42			48-HR @(7.0 LB/2-PERSON-DAY)	
TEMP AND HUMIDITY CONTROL		102			FANS/SEPARATORS, HEAT EXCHANGER, ETC	
TRACE CONTAMINANT CONTROL		7			CANISTER FOR IMPURITY REMOVAL	
DUCTING, MISC		20			FANS INCLUDED IN TEMPERATURE CONTROL	
EQUIPMENT COOLING			209			
EQUIPMENT COLD PLATES		120			S= 60 SF @ 2.0 PSF	
AVIONICS COOLING ASSY		28			INCL HX, FANS, DUCTING	
IMU HEAT EXCHANGER ASSY	1	31				
PLUMBING		20				
DUCTING, MISC		10			FANS INCLUDED IN TEMPERATURE CONTROL	
HEAT TRANSFER WATER LOOP			141			
HEAT EXCHANGER - POTABLE WATER	1	17			BASED ON SHUTTLE	
PRIMARY, SECONDARY WATER PUMPS		78				
PLUMBING		21				
COOLANT IN LOOP - WATER		25				
HEAT TRANSFER FREON LOOP			270			
HEAT EXCHANGER - WATER-FREON	1	50			BASED ON SHUTTLE	
HEAT EXCHANGER - GSE	1	50			BASED ON SHUTTLE	
HEAT EXCHANGER - FUEL CELL	1	50			BASED ON SHUTTLE	
FREON PUMP PACKAGE	2	90				
COOLANT IN LOOP - FREON		30				
HEAT REJECTION			222			
AMMONIA BOILER ASSEMBLY		45			INCL AMMONIA TANK, HEAT EXCHNGR, VENT, VALVES	
COOLANT TANKAGE - WATER		14				
FLASH EVAPORATOR - WATER		58			FROM SHUTTLE	
TOPPING DUCT ASSEMBLY		78				
HIGH LOAD DUCT ASSEMBLY		27				
RADIATOR PANELS			0		INCL ON AFT ADAPTER	
ECLSS SUPT/INSTL			119		10 % OF ECLSS	

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 9 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
PERSONNEL PROVISIONS				978		15
FOOD MANAGEMENT			117			
GALLEY		0			GALLEY UNIT, WITH WATER DISPENSER	
FOOD STORAGE UNITS		117				
WATER MANAGEMENT			52			
WATER STORAGE TANK	2	17			FOR POTABLE WATER STORAGE	
HANDWASH - WET WIPES		2				
WATER DISPENSER		23			WATER DISPENSER ONLY	
PLUMBING, VALVES, ETC		10				
WASTE MANAGEMENT			47			
WASTE WATER TANK	2	17				
COMMODE SYSTEM		15			installation scar only for crew rotation	
EMERGENCY WASTE COLLECTION		15			SHUTTLE TYPE	
FIRE DETECTION / SUPPRESSION			13			
SMOKE DETECTORS		7				
FIRE SUPPRESSION TANK		6			INCLUDES SUPPRESSANT	
FURNISHINGS AND EQUIPMENT			660			
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS	2	200			INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS					INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SEATS, PERSONNEL RESTRAINTS					INCL FLIGHT SEAT, RESTRAINT, IMPACT ATTENUATION	
SLEEP STATIONS		0			NOT REQUIRED FOR TRANSFER	
INCIDENTAL EQUIPMENT	6	60			STORAGE FOR ASTRONAUT PERSONAL EFFECTS	
SUPPORT/INSTALLATION			89		10 % OF ECLSS	
CREW MOD DRY, EXCL GROWTH				21144		14.2
WEIGHT GROWTH MARGIN				3172	14 % OF DRY WT	
CREW MODULE DRY WEIGHT				24316		

BOEING

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 10 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS	WG%
NON- CARGO ITEMS				**2958**		
CREW, WITH EQUIPMENT			1800			
FLIGHT CREW / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects	2	600			90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects					90TH PERCENTILE + 107 lb ea.	
PASSENGERS / personal effects					90TH PERCENTILE + 107 lb ea.	
TOOLS, MISCELLANEOUS	0	0				
EVA SUITS, WITH EXPENDABLES	0	0				
PROPELLANT RESIDUALS			393			
OMS RESIDUALS - IN TANKS		73			0.3 FT3 PER TANK	
OMS RESIDUALS - IN LINES, ENGINES		132			8 FT EA, 5.0 IN DIA.	
OMS PRESSURANTS		78			0.0251 LB/LB PROPELLANT NITROGEN	
RCS RESIDUAL BI-PROP		46			RESIDUAL IN TANKS AND LINES	
RCS N2 PRESSURANT		18				
COLD GAS RESIDUALS		45				
PROPELLANT RESERVES			765			
OMS RESERVES		284			10% OF NOMINAL	
RCS RESERVES - BIPROP		269			20% OF NOMINAL PROPELLANT	
RCS RESERVES - COLD GAS		212			20% OF NOMINAL PROPELLANT	
PAYLOAD / CARGO				**0**	**NO CARGO CAPABILITY**	
CREW MODULE INERT WEIGHT				**27274**		

ITEM	QTY	VALUE			REMARKS	WG%
NON- PROPELLANT				**696**		
IN-FLIGHT LOSSES			334		(CR- 264 KW-HR; SS- 840 KW-HR)	
FUEL CELL NOMINAL O2		238			0.71 LB/ KW -HR	
FUEL CELL NOMINAL H2		30			0.09 LB/ KW-HR	
FUEL CELL O2 RESERVES		48			20% NOMINAL	
FUEL CELL H2 RESERVES		6			20% NOMINAL	
FUEL CELL RESIDUAL REACTANT		13			ESTIMATE	
LIFE SUPPORT CONSUMABLES			362			
O2 - CRYO STORAGE		24			METABOLIC CONSUMPT. (2 LB/M-DAY) +20%	
O2 - GAS FOR REPRESSURIZATION		9			1 repress contingency + leak (0.38 LB/DAY)	
O2 - CABIN PRESSURIZATION		8				
N2 - GAS FOR REPRESS, LOSSES		40			1 repress contingency + leak (1.26 LB/DAY)	
N2 - CABIN PRESSURIZATION		38				
FOOD - nominal		40			4 LB/M-DAY	
FOOD - contingency		48			4 LB/M-DAY -- 48 hr contingency	
POTABLE WATER - nominal		0			4 LB/M-DAY supplied by fuel cells	
POTABLE WATER - contingency		55			4 LB/M-DAY --48 HR CONTINGENCY + resid	
EQUIP COOLING FLUIDS - AMMONIA		45			WATER FOR LAUNCH & REENTRY COOLING ONLY + 20 %	
EQUIP COOLING FLUIDS - WATER		55			WATER FOR LAUNCH & REENTRY COOLING ONLY + 20 %	

Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 11 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	VALUE			REMARKS		WG%
PROPELLANT - NOMINAL				3393			
RCS NOM PROPELLANT - BIPROP			402				
RCS NOM PROPELLANT - COLD GAS			151				
OMS NOMINAL PROPELLANT			2840		DELTA V AS SHOWN		
GROSS WEIGHT				31363			
ADAPTER / RADIATOR MODULE				2256			
STRUCTURE			989				
AFT ADAPTER INTERFACE RING	1	158			L=43 FT, A=3.0 IN2	ALUMINUM	
CREW MODULE INTERFACE RING	1	92			L=30.6 FT, A=2.5 IN2	ALUMINUM	
MINOR FRAMES	2	134			L=37.3 FT, A=1.5 IN2	ALUMINUM	
LONGERONS	6	257			L=11.9 FT, A=3.0 IN2	ALUMINUM	
INTERMEDIATE STRUTS / FTGS	18	248			L ave=7.1 FT, A=1.0 IN2 +1.0 LB FTGS	ALUMINUM	
RADIATOR PANEL LINKAGE & HINGES	2	40					
LAUNCH / CREW MOD UMBIL PLATES	2	60					
THERMAL PROTECTION			71		S= 1034 SF, @ 0.0685 PSF	FOSR	
POWER DISTRIBUTION			188				
WIRING, INCL GROUND UMBILICALS		150					
EQUIPMENT SUPPORT/INSTL		38			25 % OF WIRING	ALUMINUM	
ECLSS RADIATOR PANELS			564				
COOLANT IN PANELS - FREON		30					
FIXED PANELS	2	304			A=134 sf ea @ 1.14 psf	ALUMINUM	
DEPLOYED PANELS	2	230			A=67 sf ea (67 sf ea side) @ 1.72 psf	ALUMINUM	
OTHER - AUXILIARY SYSTEMS			150				
LAUNCH VEHICLE SEPARATION	6	90			EXPLOSIVE BOLT SEPARATION		
CREW MODULE SEPARATION	6	60			EXPLOSIVE BOLT SEPARATION		
WEIGHT GROWTH MARGIN			294		15 % OF HARDWARE		
GROSS WEIGHT				33619			
LAUNCH VEHICLE ADAPTER				1956			
STRUCTURE			1363		S= 545 SF @ 2.5 PSF	ALUM SKIN/STR	
PROTECTION - THERMAL			0				
POWER - WIRE HARNESS			188		L= 8 FT, INCL CONNECTORS, ETC		
OTHER - CREW MOD SEPARATION SYS	6		150		SEP BOLTS		
WEIGHT GROWTH MARGIN			255		15 % OF HARDWARE		
BALLAST				0			
FWD NOSE BALLAST			0				
TOTAL LAUNCH WEIGHT				35575			

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Table 21.3-12 Detailed Mass Properties for Configuration IV (6 Person) (Page 12 of 12)

GROUP WEIGHT STATEMENT
Winged PLS Concept #4 (10 Personnel, Tile TPS)

NOTE: ALL MASS IN POUNDS

ITEM	CREW ROTATION QTY	CREW ROTATION VALUE	REMARKS	WG%
SEQUENCED MASS DATA				
TOTAL WEIGHT		35575		
SEPARATE FROM LAUNCH VEH ADAPTER		-1956		
ON-PAD ABORT WEIGHT		33619		
JETTISON LAUNCH ESCAPE ENG, FEED		-2543		
JETTISON LAUNCH ESCAPE THRUST STR		-178		
ON-ORBIT WEIGHT		30898		
DELETE CONSUMABLES TO REENTRY		-69		
DELETE POWER FLUIDS TO REENTRY		-263		
DELETE NOMINAL RCS ON-ORBIT PROP		-290		
DELETE PROX OPS COLD GAS		-151		
DELETE OMS ON-ORBIT PROP		-2840		
SEPARATE SERVICE MODULE		0		
SEPARATE RADIATOR MODULE		-2256		
BEGIN REENTRY WEIGHT		25030		
DELETE CONSUMABLES		-13		
DELETE REENTRY POWER FLUIDS		-5		
DELETE NOMINAL RCS REENTRY PROP		-112		
LANDING WEIGHT		24900		

21.4 Abort

To evaluate the abort trajectories during ascent, a generic model was created that has the capability of infinitely varying aerodynamic characteristics for the PLS vehicle. It was assumed that a LES with a ΔV of around 1000 ft/s (expended in a brief time period) was available for any configuration. After LES burnout, the PLS could maneuver to its best advantage to attempt to reach land (assuming an easterly launch from KSC).

In the first analysis, trajectories were optimized for maximum downrange to determine when a glide to Africa was possible for a configuration with excellent aerodynamics (hypersonic L/D=1.5, subsonic L/D=5.0). Several abort times (defined as the elapsed time between ground launch ignition time and the ignition of the LES motor(s)) are shown on a 28.5° ground track on Figure 21.4-1. These times are fairly insensitive to booster selection, as all vertical takeoff rockets tend to fly the same ascent profile. Note that approximately 370 seconds into the flight is about the minimum time that would result in a successful glide to Africa. Note also the maximum footprint lines for maximum downrange trajectories that incorporate banking.

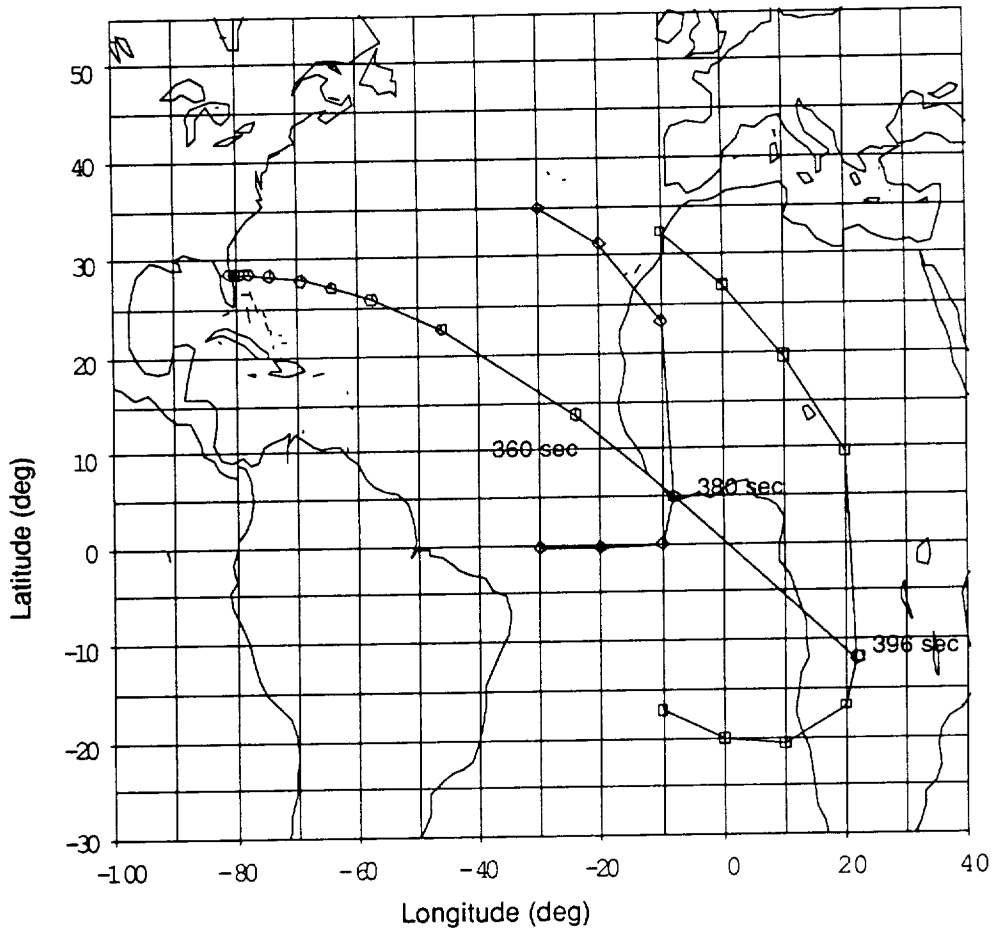

Figure 21.4-1 Abort Glides for Lifting PLS on 28.5° Inclination Trajectory

Return to launch site (RTLS) aborts were also examined (see Figure 21.4-2). In this case the object was to minimize the landing longitude. Abort times are shown for each corresponding landing point. Maximum ascent time for successful returns to Florida occurs at around 100 seconds into the booster burn. For abort times greater than this, insufficient range exists to fly back to Florida.

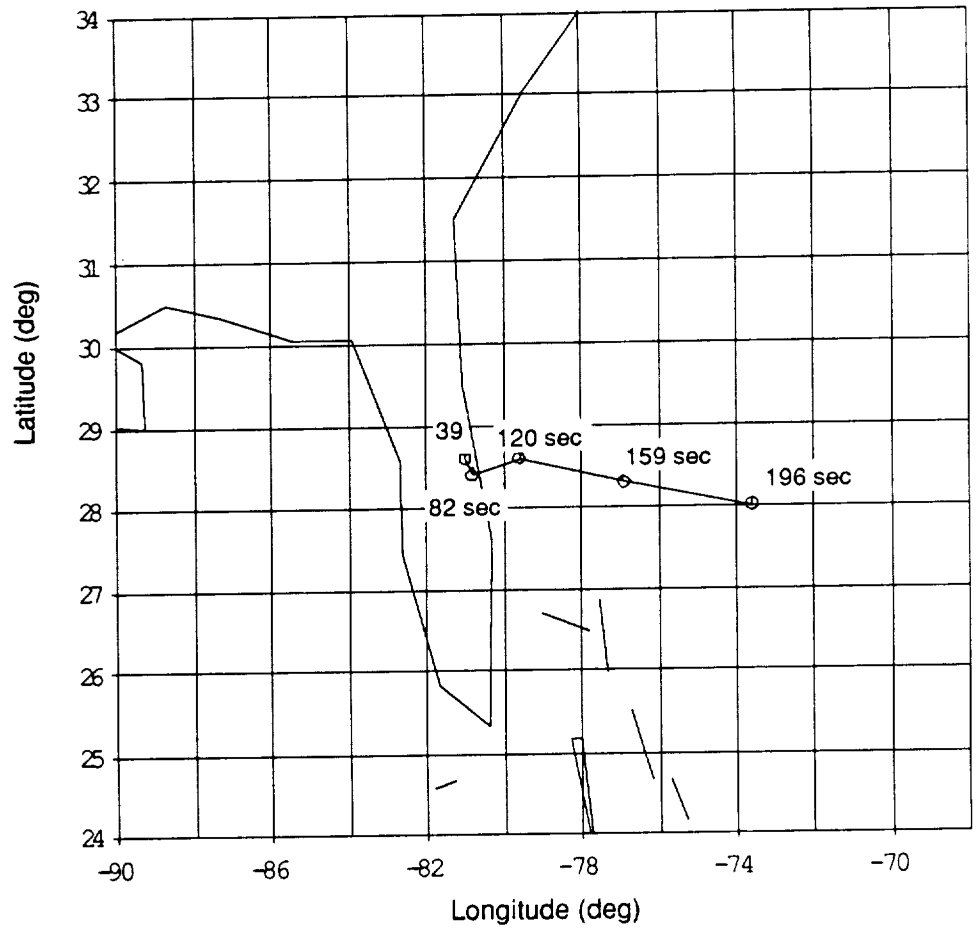

Figure 21.4-2 RTLS Abort Capability

For a less capable vehicle, the ability to fly to land is diminished. For example, a vehicle with a hypersonic L/D of 1.2 (subsonic L/D=4.0) would require an additional 10 seconds of ascent time to be able to glide to Africa (see Figure 21.4-3).

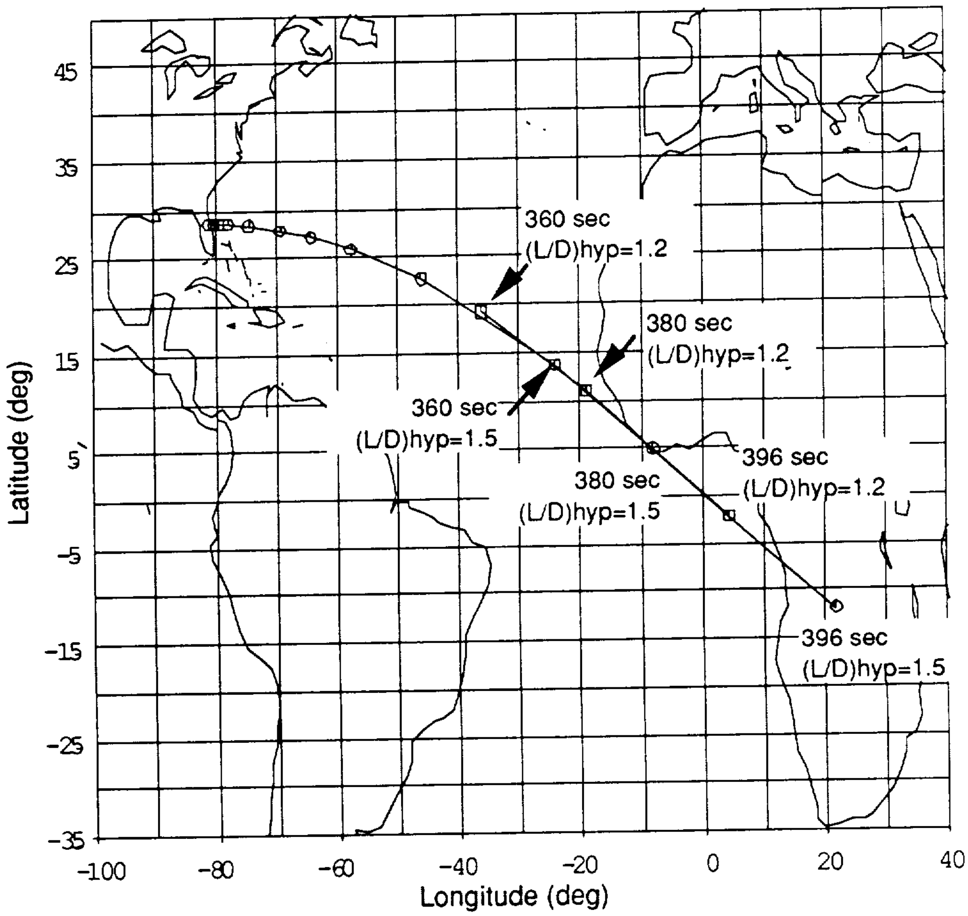

Figure 21.4-3 Effect of L/D on Abort Capability

The effect of vehicle mass was also examined. The PLS mass was varied parametrically between 20,000 lbm and 60,000 lbm but was found to make no appreciable difference in the abort times.

The effect on inclination does, however, affect the abort situation. For higher inclinations, such as a 57° launch, the boost track parallels the North American landmass for a significant period of time. Figure 21.4-4 depicts the landing zones available for various abort times. During most the ascent, a land landing site could be reached with the exception of a short (~80 seconds) period immediately after liftoff when a water abort is inevitable.

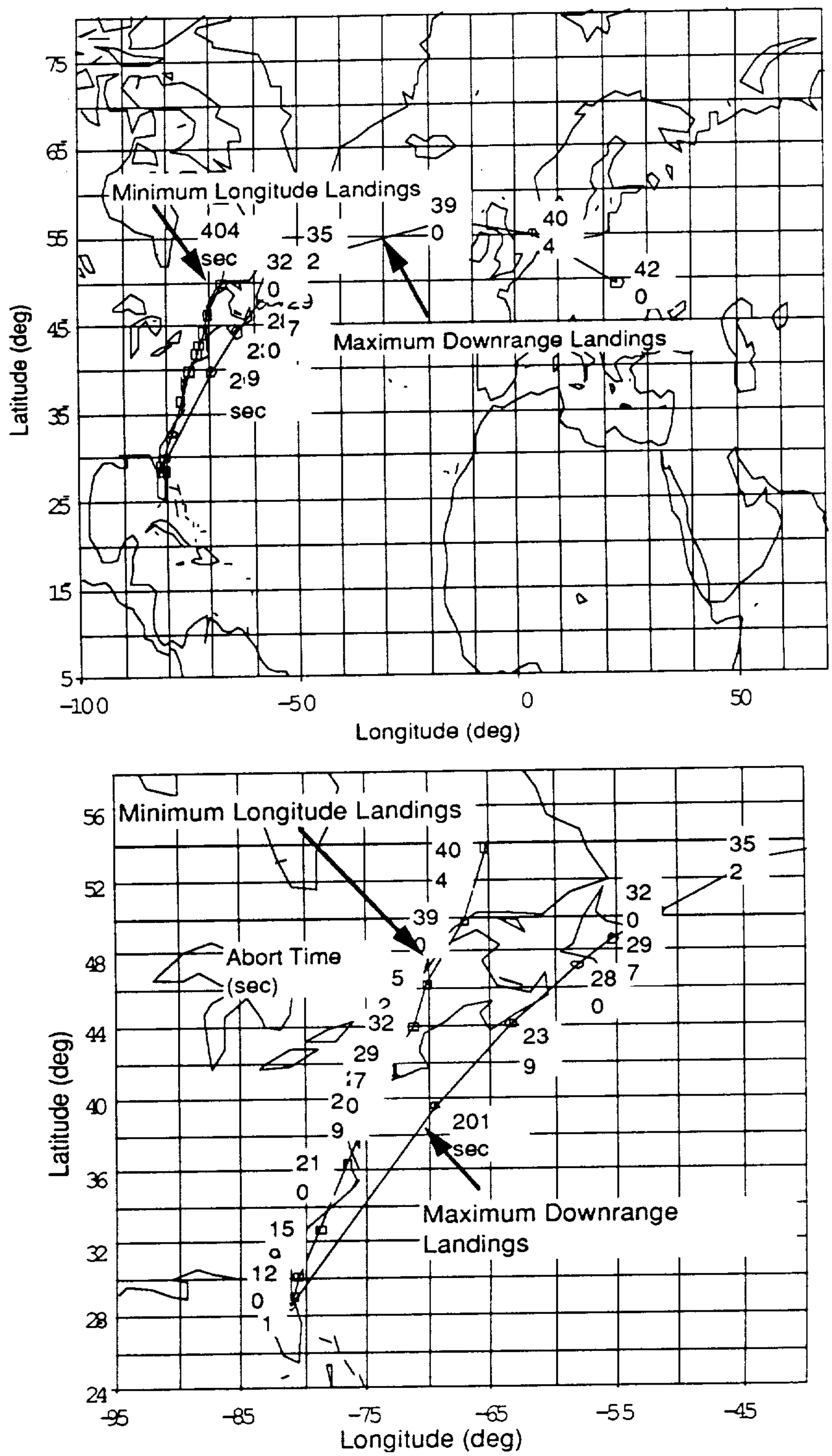

Figure 21.4-4 Abort Track for 57° Inclination Trajectory

In conclusion, there is a significant portion of the ascent trajectory from which an abort will result in a landing in the Atlantic Ocean, even with a high L/D vehicle turning towards land. Provisions for water landed should therefor be included in all PLS designs.

21.5 Special Issues

In addition to the specific analyses performed in support of the four configurations, several special topics were examined that are applicable to the whole range of PLS concepts.

21.5.1 Utilization of SSF Resources

Early in the previous study phase, a self-imposed groundrule was stated that said the PLS would not utilize any resources from the SSF, with the only interface being the physical docking mechanisms and some form of local communications link. At that time, it was felt that the SSF's capabilities for power, cooling, etc. were only sufficient for the SSF. Any additional demands for resources from the SSF could be detrimental to the station's performance as well as providing a negative (and unnecessary) view of the PLS program. In addition, counting on hook-ups to perform the PLS mission introduces new flight critical failure modes and leaves no margin or robustness for alternate missions.

There are, however, certain scenarios where using the SSF's resources while the PLS is docked would be beneficial. Certain subsystem selections could change based on the reduction in total resources required to perform DRM 1. To explore the effect of using SSF, four alternative scenarios were considered. The first, reference scenario is based on the previous study work; that is, the PLS would supply all of it's own electrical power, thermal control, and expendables associated with a rotation mission where the two pilot-astronauts would remain onboard the PLS and the passengers would disembark and "live" on the SSF during the time of SSF crew transition. The second scenario again features independent PLS capabilities, sized in this case for ten people to be "living" in the PLS at all times. The PLS occupants would require resources for eating, thermal control, lighting, etc. that were distinct from those in the SSF. The third scenario is similar to the first in that the flight crew of 2 remains in the PLS, but in this case, a connection was made that enables the SSF to provide all power and thermal control for the PLS. The fourth scenario is where no one remains onboard the PLS and the SSF is providing the necessary power and thermal control for the PLS vehicle. The requirements for the EPS and TCS onboard the PLS are summarized in Table 21.5.1-1.

Table 21.5.1-1 Power and Thermal Requirements for Four SSF/PLS Operating Scenarios

		SSF-Staytime Options			
	Sat. Service	1 - Reference	2	3	4
	4 crew on-board all PLS-supplied	2 crew on-board all PLS-supplied	10 crew onboard all PLS-supplied	2 crew on-board SSF-supplied power / thermal	0 crew on-board all SSF-supplied
Launch					
Time, hr	1.00	1.00	1.00	1.00	1.00
No. Crew	4.00	10.00	10.00	10.00	10.00
Ave. Power, kw	5.97	5.97	5.97	5.97	5.97
Ave. Thermal reject, kw	8.80	9.58	9.58	9.58	9.58
Tot. Energy Consumed (kw-hr)	5.97	5.97	5.97	5.97	5.97
Tot. Energy Rejected (kw-hr)	8.80	9.58	9.58	9.58	9.58
Tot. Person-days	0.17	0.42	0.42	0.42	0.42
Rendezvous					
Time, hr	24.00	12.50	12.50	12.50	12.50
No. Crew	4.00	10.00	10.00	10.00	10.00
Ave. Power, kw	6.18	6.18	6.18	6.18	6.18
Ave. Thermal reject, kw	9.40	10.20	10.20	10.20	10.20
Tot. Energy Consumed (kw-hr)	148.34	77.26	77.26	77.26	77.26
Tot. Energy Rejected (kw-hr)	225.60	127.48	127.48	127.48	127.48
Tot. Person-days	4.00	5.21	5.21	5.21	5.21
Docked at SSF					
Time, hr	124.00	53.00	53.00	53.00	53.00
No. Crew	4.00	2.00	10.00	2.00	0.00
Ave. Power, kw	4.28	3.98	4.28	0.00	0.00
Ave. Thermal reject, kw	5.00	4.81	6.20	0.00	0.00
Tot. Energy Consumed (kw-hr)	530.72	210.81	226.84	0.00	0.00
Tot. Energy Rejected (kw-hr)	620.00	259.86	333.70	0.00	0.00
Tot. Person-days	20.67	4.42	22.08	4.42	0.00
Deorbit, reentry, landing					
Time, hr	6.00	5.50	5.50	5.50	5.50
No. Crew	4.00	10.00	10.00	10.00	10.00
Ave. Power, kw	6.18	6.18	6.18	6.18	6.18
Ave. Thermal reject, kw	9.00	9.80	9.80	9.80	9.80
Tot. Energy Consumed (kw-hr)	37.08	33.99	33.99	33.99	33.99
Tot. Energy Rejected (kw-hr)	54.00	53.89	53.89	53.89	53.89
Tot. Person-days	1.00	2.29	2.29	2.29	2.29
Total					
Time, hr	155.00	72.00	72.00	72.00	72.00
Tot. Energy Consumed (kw-hr)	722.11	328.03	344.06	117.22	117.22
Tot. Energy Rejected (kw-hr)	908.40	450.80	524.64	190.94	190.94
Tot. Person-days	25.83	12.33	30.00	12.33	7.92

With these requirements, key subsystem options were examined to find the best subsystem selection consistent with the envisioned mission scenario. For example, for the EPS, three options were considered: the reference system which uses two fuel cells and a contingency battery backup, an all fuel cell system, and an all battery system. Mass comparison data is shown as Table 21.5.1-2 and plotted versus energy required in Figure 21.5.1-1. The dotted lines on the plot correspond to the various SSF options discussed earlier. As one would expect, for the options where the PLS can tap into the SSF, a simple battery system is lightweight and probably more reliable. For the options were the SSF's EPS is not used, the weight penalty for batteries is significant. For comparison then, SSF options 1 and 2 will use a fuel cell/battery combination and options 3 and 4 will use a battery only system.

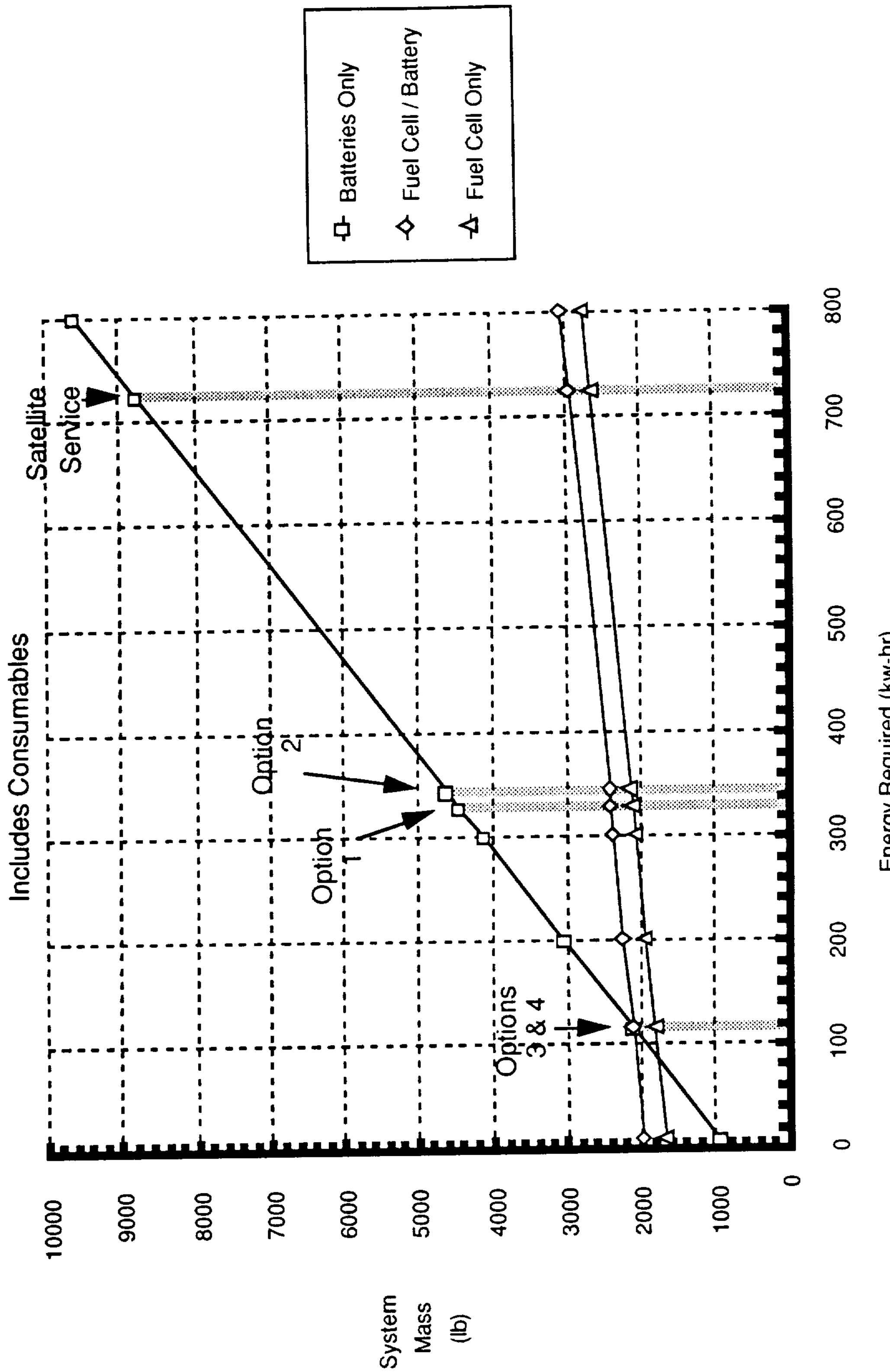

Figure 21.5.1-1. Mass Trending for EPS Options

Table 21.5.1-2 Options for EPS

	1 - Reference	2	3
Power	Fuel Cell / Battery	Fuel Cell Only	Batteries Only
Fixed hardware mass - lb	1944.00	1655.00	825.00
Power source - fuel cells	415.00	623.00	0.00
Power source - batteries	497.00	0.00	0.00
Reactant Supply Plumbing	175.00	175.00	0.00
Distribution & Cntrl Equipment	169.00	169.00	169.00
Wiring, fixed	688.00	688.00	656.00
Variable mass - lb/kw-hr	1.36	1.36	11.00
Power source - variable	0.00	0.00	10.35
Reactant Supply Tankage	0.40	0.40	0.00
Wiring, variable	0.00	0.00	0.65
Consumables	0.96	0.96	0.00
Total - lb			
10 kw-hr	1958	1669	935
117 kw-hr	2103	1814	2112
200 kw-hr	2216	1927	3025
300 kw-hr	2352	2063	4125
328 kw-hr	2390	2101	4433
344 kw-hr	2412	2123	4609
722 kw-hr	2926	2637	8767
800 kw-hr	3032	2743	9625

For the TCS, four options were considered. The first reference option is, as previously used in this study, a mix of radiators (expendable) and boiler/evaporators that reject 98% and 2% of the waste heat respectively. The second option again features a mix of radiators (60% of total heat rejected) and boilers (40%). The third option is another mix of these same devices at a 40%/60% ratio. The fourth option would only use boilers, eliminating entirely the radiator hardware. Table 21.5.1-3 and Figure 21.5.1-2 depict the data for these various options versus the total rejected energy requirement. Note that the consumables associated with the all boiler option are prohibitively heavy for options where the PLS is not connected to the SSF TCS. Also note that if a radiator system is included, one wants to maximize its utilization (98% of total heat load). This assumes the radiator is expendable. A smaller, recoverable radiator could be features at the expense of boiler expendables mass. For the four SSF options considered, then, options 3 and 4 (plugged into the SSF TCS) a boiler system for ascent/descent would be best; for options 1 and 2 that operate independently of SSF, a radiator/boiler system (98%/2%) would be best.

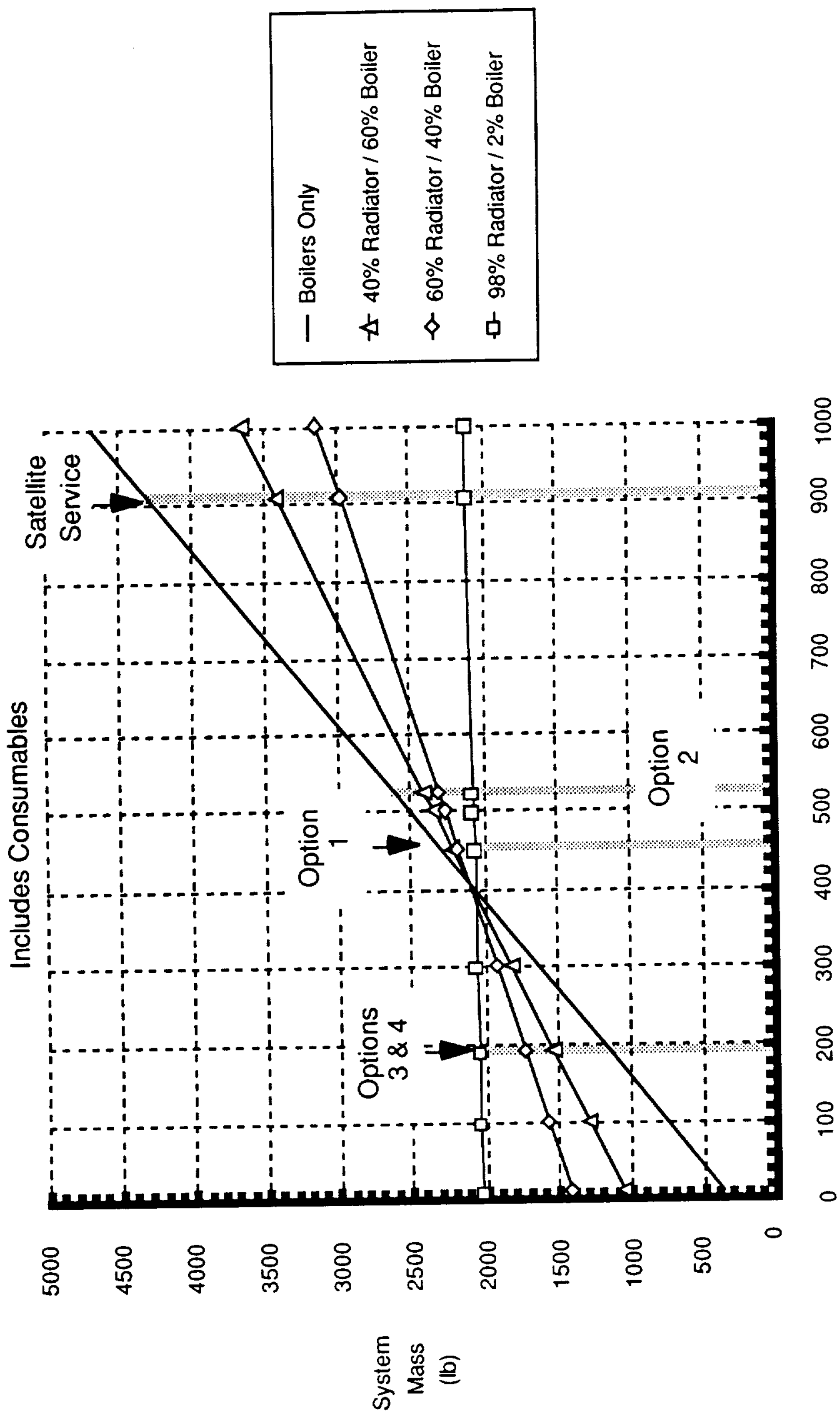

Figure 21.5.1-2. Mass Trending for TCS Options

Table 21.5.1-3 Options for TCS

Thermal Rejection		Radiator / Boiler 98% / 2%	Radiator / Boiler 60% / 40%	Radiator / Boiler 40% / 60%	Boilers Only
Fixed hardware mass - lb		2027.00	1390.00	1023.00	321.00
Ammonia Boiler - fixed		45.00	45.00	45.00	45.00
Water Flash Evaporator - fixed		58.00	116.00	116.00	145.00
Coolant Tankage - constant		6.00	6.00	6.00	6.00
Duct Assemblies - fixed		105.00	105.00	105.00	105.00
Coolant - fixed (launch/reentry)		20.00	20.00	20.00	20.00
Radiator Panels - fixed		795.00	487.00	324.00	0.00
Radiator Support - fixed		998.00	611.00	407.00	0.00
Variable mass - lb/kw-hr		0.09	1.74	2.62	4.36
Coolant Tankage - Variable		0.02	0.38	0.57	0.95
Coolant - variable		0.07	1.36	2.05	3.41
Total - lb					
10	kw-hr	2028	1407	1049	365
100	kw-hr	2036	1564	1285	757
191	kw-hr	2044	1722	1523	1154
300	kw-hr	2053	1912	1809	1629
451	kw-hr	2066	2175	2205	2287
500	kw-hr	2071	2260	2333	2501
525	kw-hr	2073	2304	2399	2610
908	kw-hr	2106	2971	3403	4282
1000	kw-hr	2114	3130	3643	4681

The other subsystem considered for varying with mission scenario involved the ECLSS. In addition to the differences in the number of onboard personnel (on the PLS), three options for potable water were considered: the reference cass were the all the water is a byproduct of the fuel cells, half the water is from the fuel cells and half was carried in tanks, and the case where all the water had to be brought from the ground in tanks. Figure 21.5.1-3 and Table 21.5.1-4 describe the rate of usage with personnel.

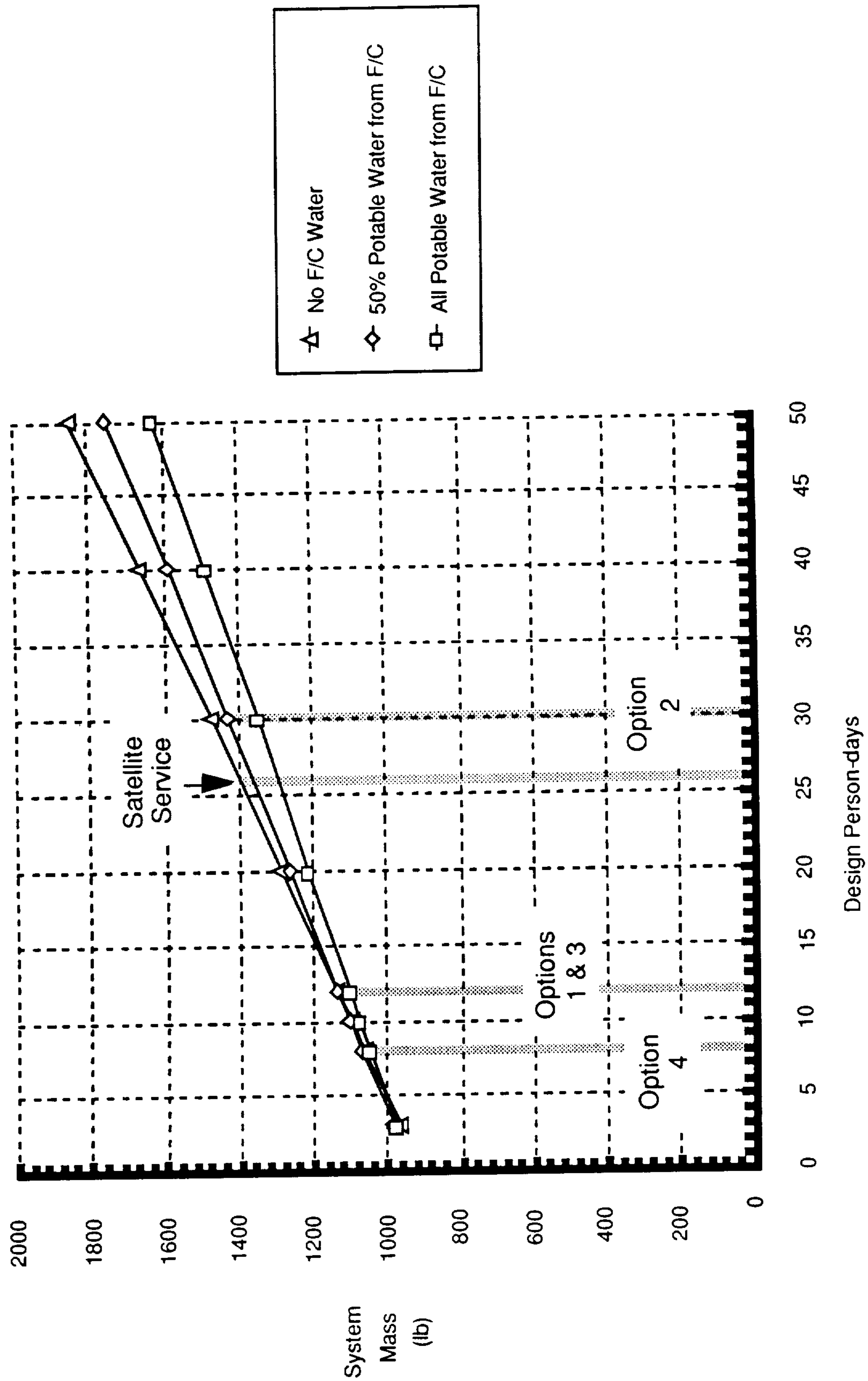

Figure 21.5.1-3. Mass Trending for ECLSS Consumables Options

Table 21.5.1-4 Options for ECLSS Consumables

ECLSS Consumables Options	1 - Reference With All F/C Water	2 With 1/2 F/C Water	3 With No F/C Water	4
Constant mass - lb	936.00	936.00	908.00	
O2/N2 Press Tankage - fixed	75.00	75.00	75.00	
Press & Composition controls	242.00	242.00	242.00	
LiOH Storage - Contingency	63.00	63.00	63.00	
Food management - fixed	73.00	73.00	73.00	
Water management - fixed	85.00	85.00	57.00	
Waste management - fixed	80.00	80.00	80.00	
O2/N2 consumables - fixed	158.00	158.00	158.00	
Food - contingency	80.00	80.00	80.00	
Potable water - contingency	80.00	80.00	80.00	
Variable mass - lb/person-day	13.73	16.29	18.85	
O2 Tankage - Variable	0.55	0.55	0.55	
LiOH Storage - Variable	3.12	3.12	3.12	
Food management - variable	3.66	3.66	3.66	
Water tankage - variable	0.00	0.56	1.12	
O2 Consumables - variable	2.40	2.40	2.40	
Food - variable	4.00	4.00	4.00	
Fuel cell water discharge	-4.00	-2.00	0.00	
Potable water - metabolic requiremnt	4.00	4.00	4.00	
Total - lb				
3 person-days	977	985	965	
8 person-days	1046	1066	1059	
10 person-days	1073	1099	1096	
12 person-days	1101	1131	1134	
26 person-days	1293	1359	1398	
30 person-days	1348	1425	1473	
40 person-days	1485	1587	1662	
50 person-days	1622	1750	1850	

Combining all the best subsystem choices into the four SSF options results in a mass comparison as shown in Figure 21.5.1-4. Using the SSF resources would, in fact, reduce the total launched PLS mass by more than 1000 lbm. Most of this difference can be attributed to leaving the radiator off the vehicle and using the SSF TCS. Leaving the flight crew onboard the PLS had little effect on the total mass.

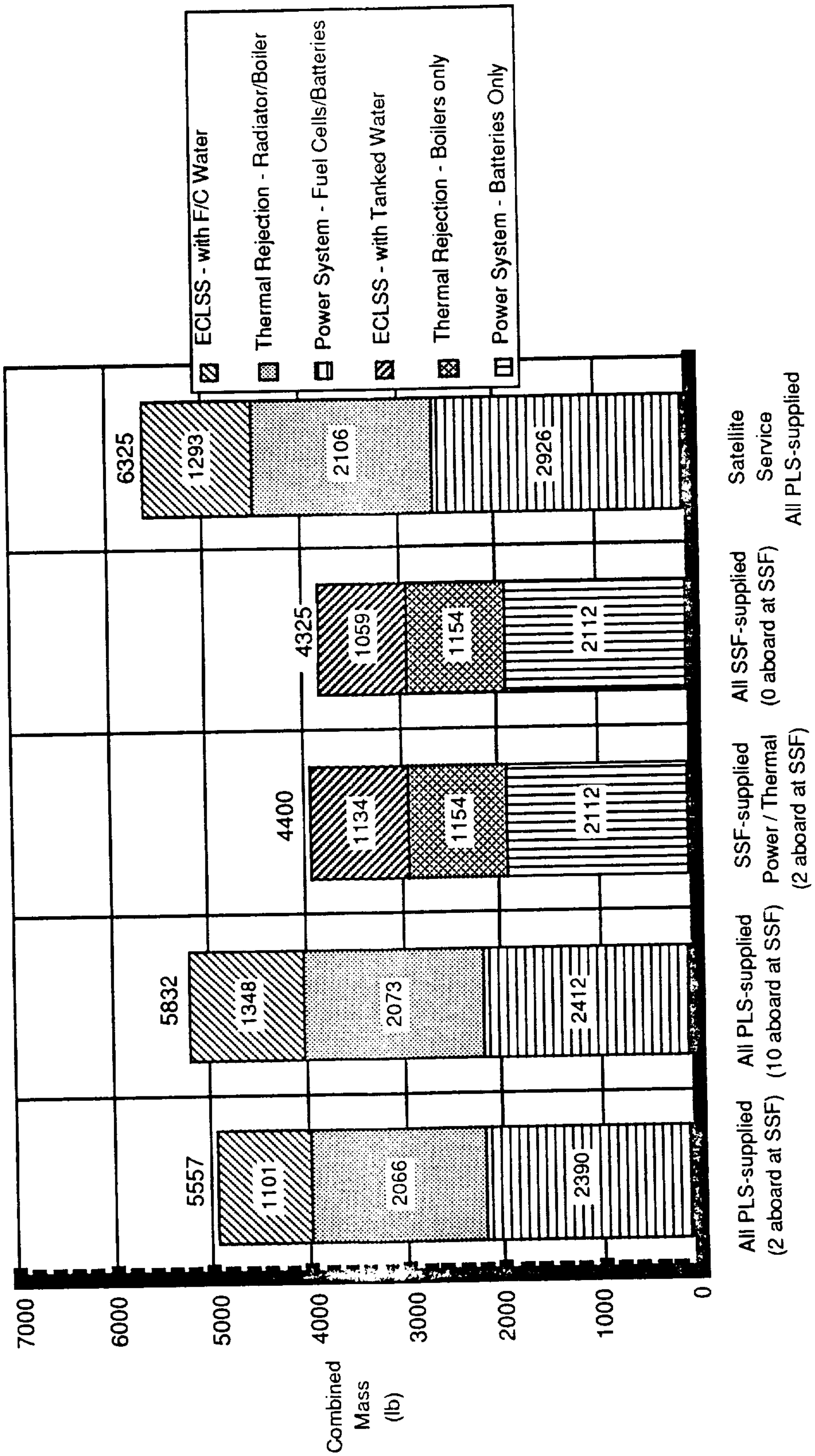

Figure 21.5.1-4. EPS/TCS/ECLSS Comparison

21.5.2 PLS/Launch Vehicle Interaction

The shape of the PLS (including launch fairings, LES, and adapters) will produce a lifting force, even at the small angles of attack encountered on a typical ELV ascent trajectory. This lift has two undesirable effects on the ascent phase of the ELV. First, the forward location of the PLS acts as a destabilizing element, moving the center of pressure (and aerodynamic center) forward much like a canard on a maneuvering airplane. In most cases, the c.p./c.g. relationship will be statically unstable requiring an active flight control systems. This can result in increased avionics complexity and may necessitate more powerful actuators (such as those on the thrust vectoring system) to meet the speed requirements for the controls. Secondly, the lift produced by the PLS creates a bending moment on the launch vehicle structure that may be outside of its structural limit. Typically, the interstage interfaces would require stiffening or redesign to accommodate some lifting configurations. Another alternative is to actively "fly" the PLS (typically using its elevons) as a load alleviation device, similar to the small canards on the B-1 bomber. Yet another alternative would involve selective placement of fairings or some device the spoil the lift capability of the PLS during ascent, although in practice this is difficult to implement. At issue here is assuring a clean separation (especially in an abort) and the additional launched mass.

Obviously, any modifications to the launch vehicle, either in structures or avionics/ software, result in a performance loss and a significant programmatic cost. The cost of launch vehicle redesign and testing has not been determined as part of this study but could become a major issue. A parametric examination of the bending moment impact of a lifting PLS on top of a launch vehicle is shown as Figure 21.5.2-1. These data are shown at "worst case" maximum dynamic pressure for the contribution of each PLS configuration forward of the nose-cylindrical tank junction. The low lift-to-drag shape contribution is essentially the same as that for a nose fairing of the same fineness ratio. The lifting body and winged vehicle configuration significantly increase the bending moment. The analysis assumed that the dynamic load with worst case wind gusts will result in a higher than normal angle of attack. The effect of angle of attack is shown for the winged configuration. Note the data shown for the limit loads of some representative ELVs. This data indicates that high lift shapes must take into account their effect on the launch vehicle.

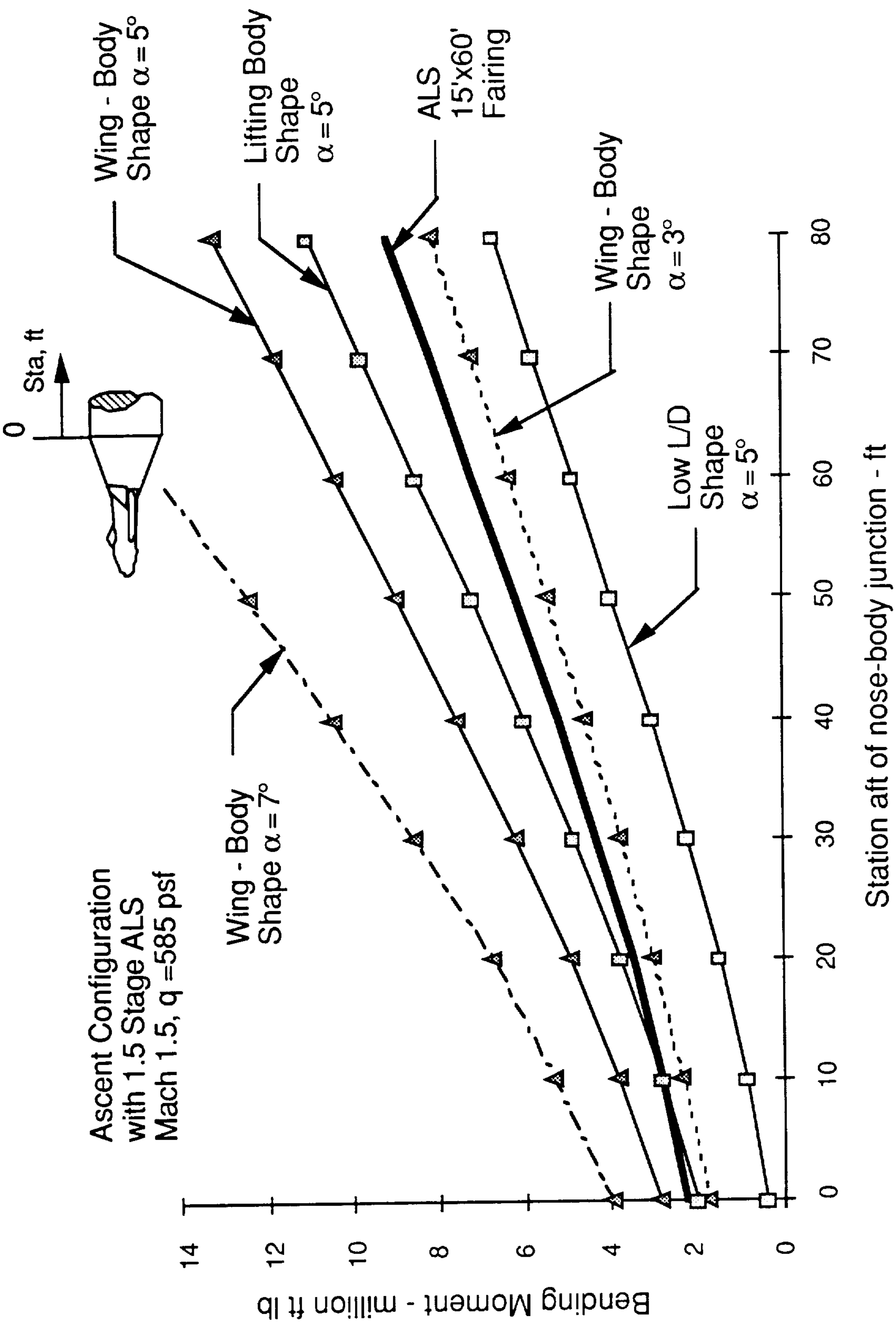

Figure 21.5.2-1. Booster Bending Moment Produced by PLS

21.5.3 Expendable Hardware Debris

On several configurations, an expendable "service module" is included to increase mission flexibility and reduce the reusable vehicle weight. This service module hardware, which typically consists of large items such as the radiator and OMS, is discarded after the deorbit burn and is expected to be destroyed during reentry. Since the PLS will fly many times, there is a finite possibility that some portion of the discarded hardware (such as a dense component like a thrust chamber) will survive reentry and impact the Earth's surface, posing a safety risk.

It is difficult to accurately predict the number or size of parts of the service module that will re-enter intact. It is also difficult to accurately predict the state of these parts or the environment they will be exposed to during re-entry. Heavier, denser pieces will enter ballistically while smaller, lighter pieces will "fly". Studies of the expendable external tank on the Space Shuttle have shown that sometimes it breaks up and burns up while other times it re-enters intact, or in large pieces. Since the Shuttle external tank is targeted for safe disposal in the ocean, it poses little risk if it is not destroyed during re-entry.

The service module hardware is similar in density and ballistic coefficient to many discarded booster elements. While it is impossible to ensure that the hardware will be destroyed during re-entry, it is possible to determine the impact zone, should anything survive re-entry.

Nominally, a PLS landing near KSC would be performed following a typical trajectory as shown in Figure 21.5.3-1. The expendable hardware can be separated anywhere from immediately after the deorbit burn to the point where dynamic pressure begins to build up (~500,000 ft altitude). It turns out that this range of release points has little influence on the ballistic impact points as shown in Figure 21.5.3-2. The initial orbital altitude does have some effect as shown in Figure 21.5.3-3. Note that a serious safety concern exists since the Texas/Northern Mexico region is directly in the path of any surviving debris. With the uncertainty associated with the aerodynamics of a tumbling service module, the dispersions could cover areas at least as large as those shown in Figure 21.5.3-4. The actual size of the dispersion ellipses depends upon the aerodynamic characteristics of any surviving pieces.

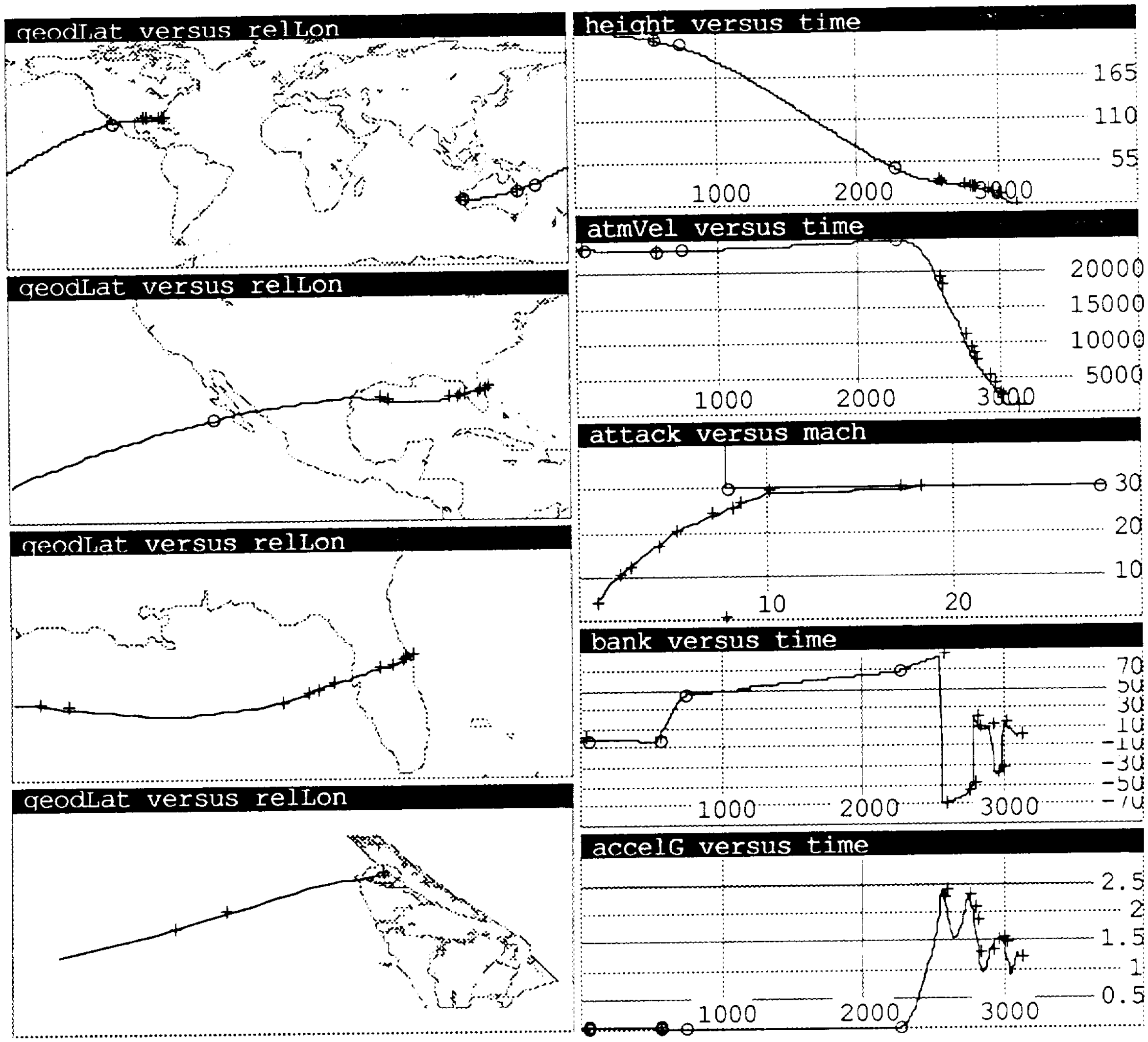

Figure 21.5.3-1 Typical PLS Reentry Trajectory

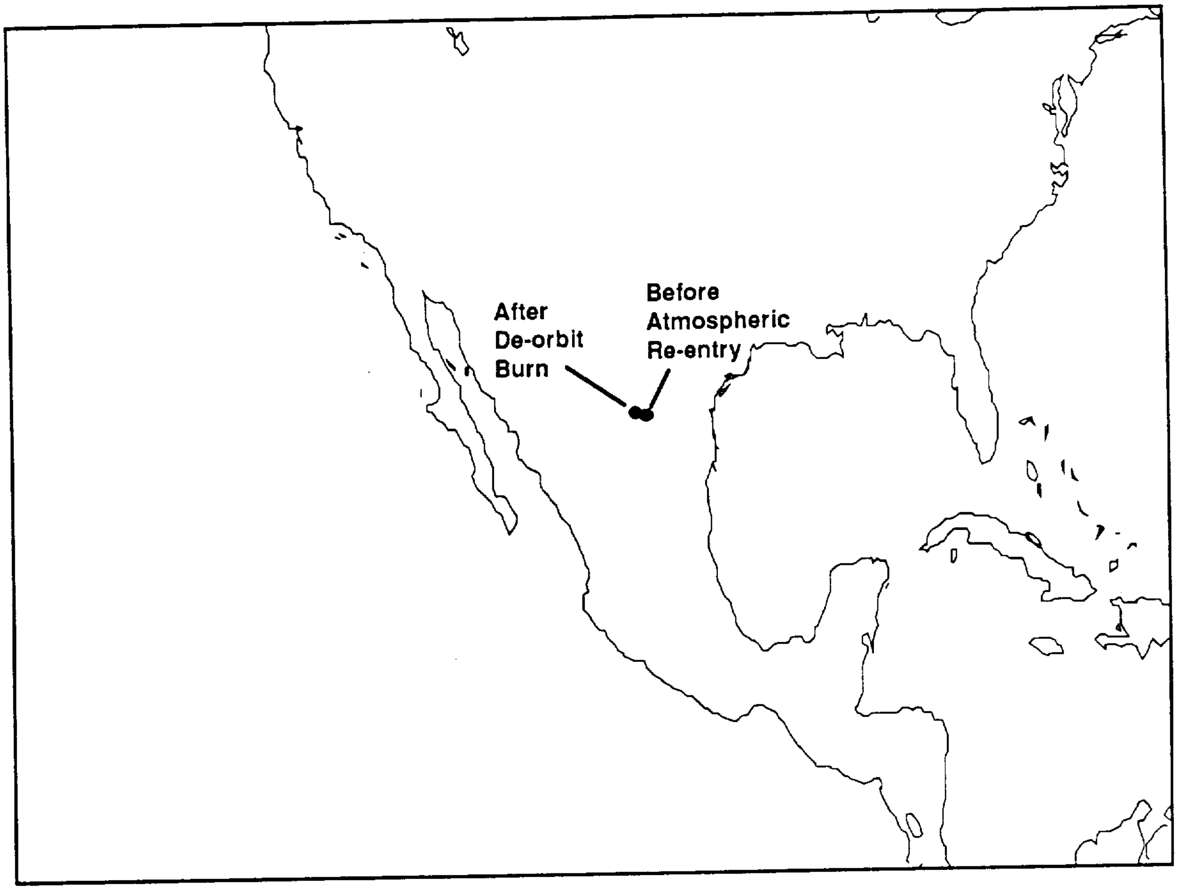

Figure 21.5.3-2 Separation Timing Effects

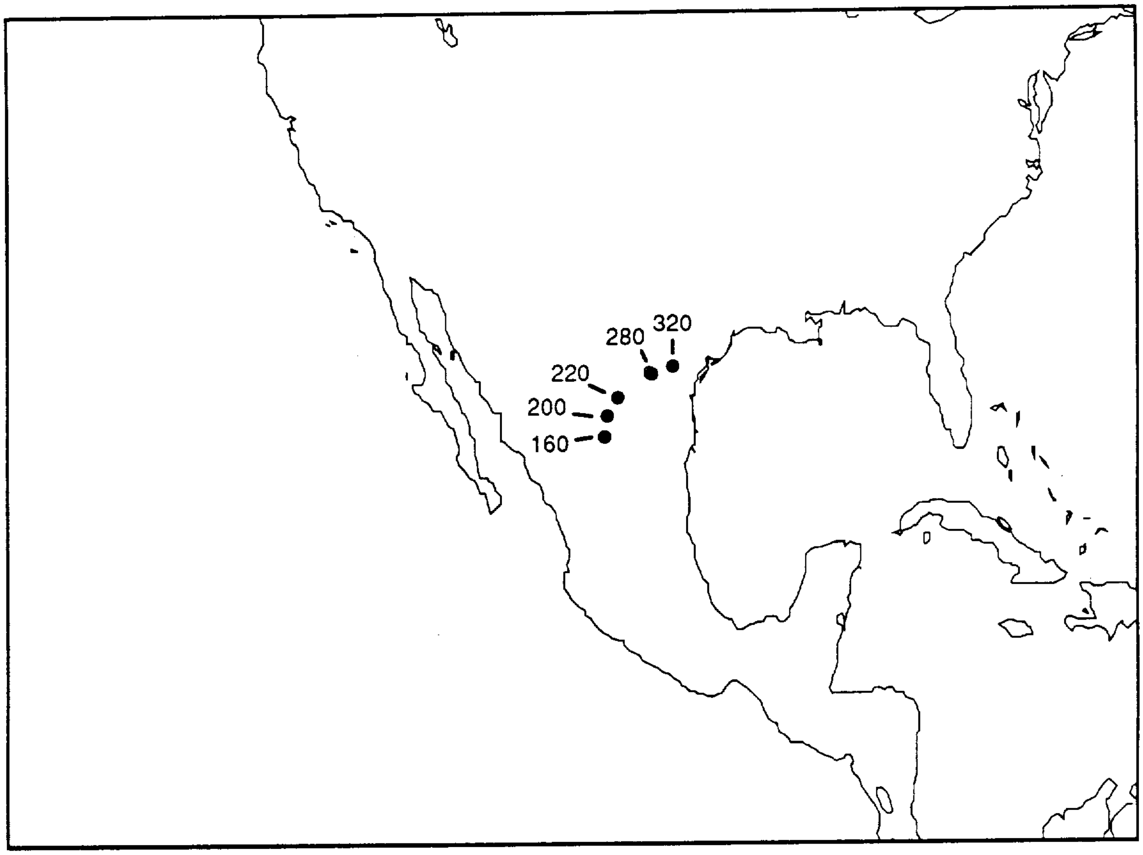

Figure 21.5.3-3 Orbital Altitude Effects

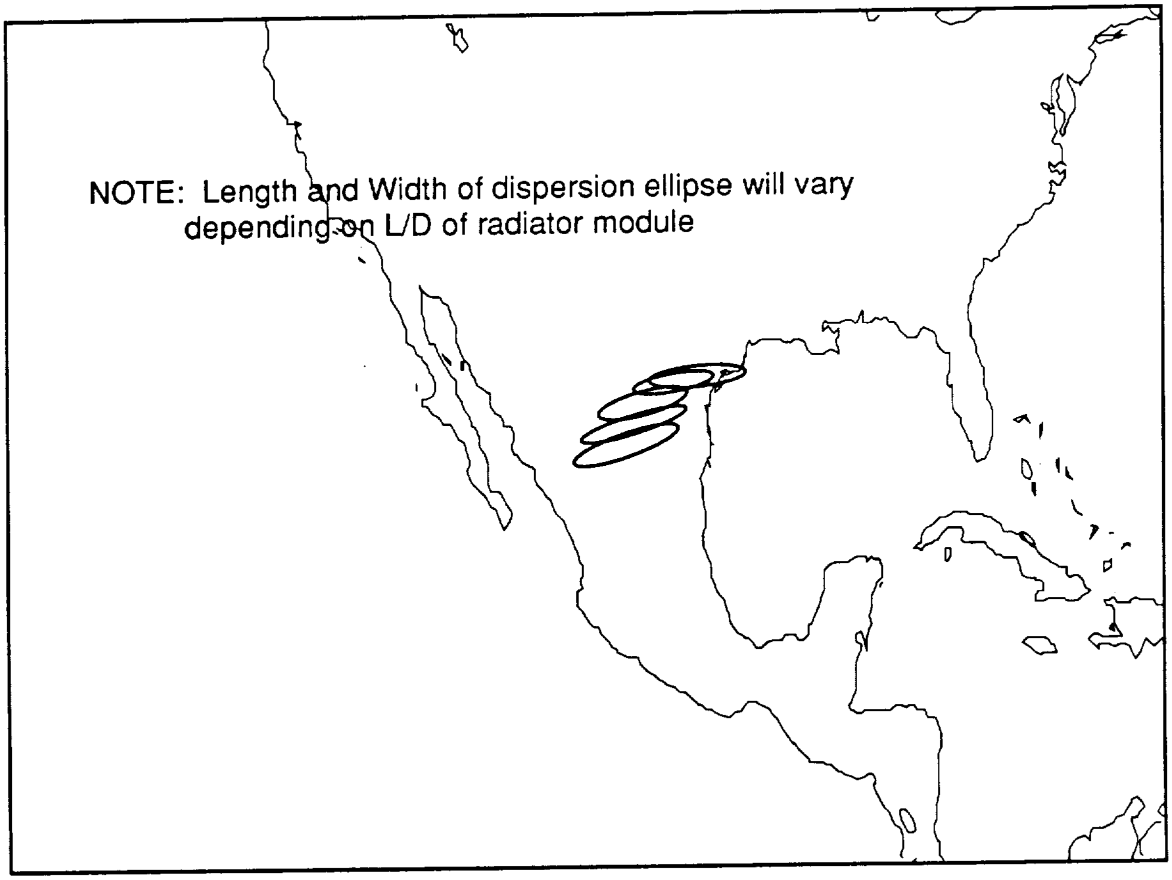

Figure 21.5.3-4 Aerodynamic Dispersion Effects

Figure 21.5.3-5 shows the ballistic impact points for a range of inclinations from which a PLS may be operating. Again, significant areas of land mass are in jeopardy, as well as coastal fishing zones.

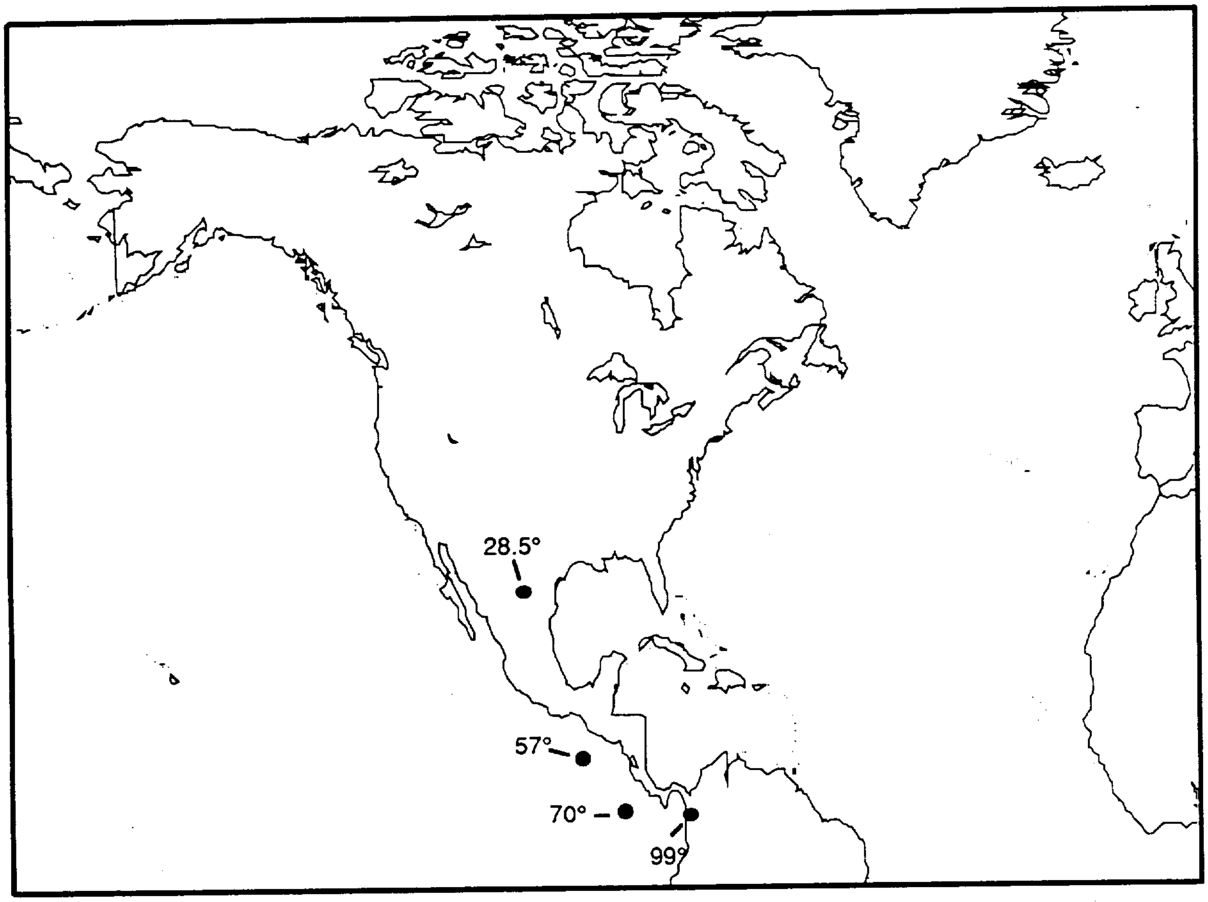

Figure 21.5.3-5 Orbital Inclination Effects

One option to reduce risk of impact would be to include ordnance that would detonate and break the service module into many small pieces that would statistically be more certain to burn up. There are obvious safety concerns for both the PLS crew and the ground processing personnel. In addition, in the past some booster explosions have resulted in the placement of debris in low Earth orbit, representing a hazard to other orbiting spacecraft.

The threat of impact damage can most effectively be reduced by propulsively targeting the impact zone so that land masses, world shipping lanes and high density fishing regions are avoided. Figure 21.5.3-6 (Reference 28) shows the estimated distribution of ships based on a projection which was made in 1973. Figure 21.5.3-7 shows that the service module ballistic impact point can be targeted to a safe region in the Pacific Ocean using a short OMS burn after separation. This method will however, require

Figure 21.5.3-6 Worldwide Ocean Shipping and Fishing Zones

ORIGINAL PAGE
COLOR PHOTOGRAPH

some additional avionics on the service module. In addition, the OMS design must take into consideration the propellant acquisition within the largely empty tanks. Alternatively, a small solid motor could be included to perform this small burn.

Post Separation
Radiator Module
De-orbit Burn

OMS Prop = 32.3 lbs
Burn Length = 11.3 sec

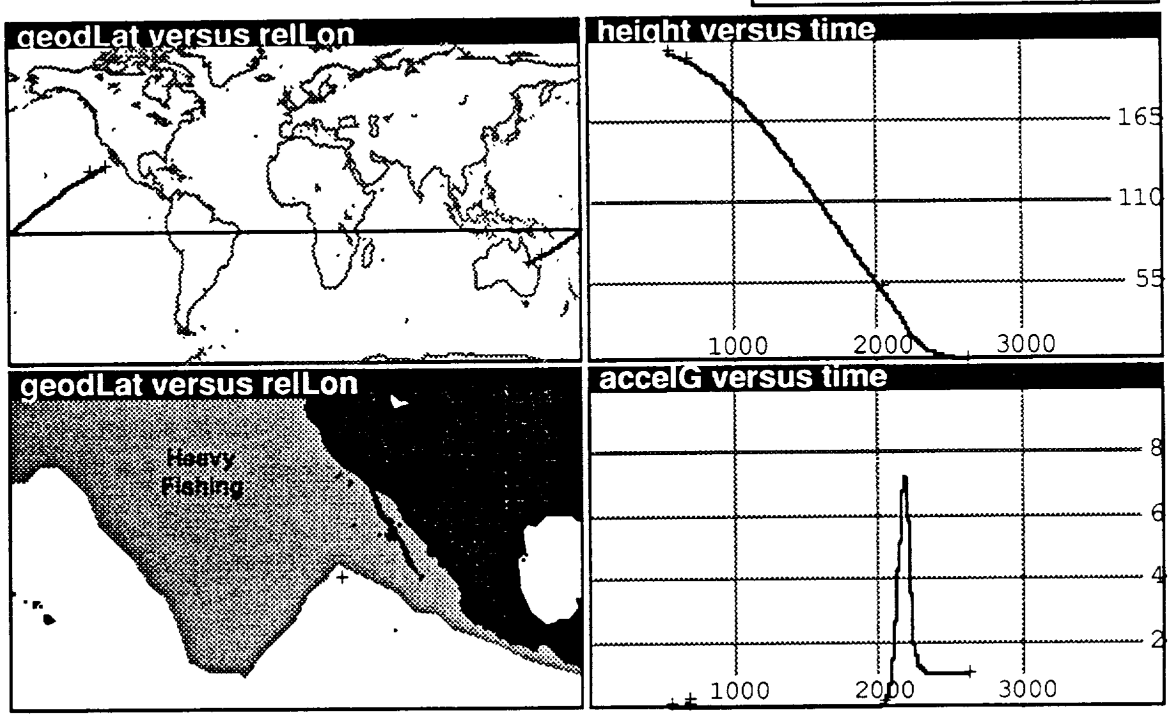

Figure 21.5.3-7 Post Separation Targeting

22 COST ESTIMATION

22.1 Basis for Cost Estimates

Cost Trade Study Systems Definition - The systems cost analysis trade study for the Modification 6 contract effort is accomplished with revised reference vehicle inputs and parametric cost model inputs consisting of technical characteristics and mass property estimates for three new Personnel Launch System (PLS) candidate configurations. The cost estimates for the four PLS representative configurations estimated are selected from a total of ten candidate configurations (see section 3 of appendix B for a complete description of the candidate configurations.)

The Boeing biconic configuration reference vehicle mass properties remained the same as those presented in the Boeing PLS basic study contract final report (presented in October of 1990.) However, some avionics and hardware estimates pertaining to the biconic design are revised for new component level cost data. The avionics cost estimates are also updated using new hardware test quantity groundrules. The Boeing biconic vehicle is presented as the reference vehicle in the systems cost analysis trade study.

New Systems Designs Selected for Cost Analysis - The three other PLS candidate configurations selected for cost estimation cover the full spectrum of aerodynamic shapes: a ballistic-shaped vehicle with a low lift-to-drag (L/D) ratio; a lifting body vehicle (similar to the Langley/Rockwell configuration); and a new winged vehicle configuration. Each vehicle candidate was pre-screened to meet specific technical performance capabilities and system requirement goals before the cost analysis trade study started.

Estimating Groundrules - The following groundrules for cost estimates apply to this preliminary PLS cost evaluation and analysis:

(1) The cost evaluation is presented in relative dollars to promote objectivity in review, per customer direction.

(2) All estimates are calculated in constant-year, 1991 dollars.

(3) Software differences are not addressed.

(4) Biconic reference vehicle is based on work statement dated 10/30/90.

(5) Test hardware quantities differ between configurations.

(6) Phase B & C/D start dates are slid 2 years from previous estimates (and schedule "penalty" is removed.)

(7) Four flight tests are assumed for each vehicle in phase C/D - two unpiloted, followed by two piloted flights.

(8) Production vehicles have an operational life of 50 reuses before major overhaul.

(9) Eastern Test Range (ETR) launch site with PLS mission control and training facilities located at Johnson Space Center.

(10) All vehicle candidate designs incorporate an integrated "pusher" LOX/RP launch escape system using a standard RS-27 engine.

(11) Primary PLS missions are Space Station Freedom (SSF) Crew Rotation and Lunar/Mars mission low Earth orbit (LEO) delivery.

(12) Secondary missions are satellite servicing and LEO observation.

(13) Three production lot buys are planned for each configuration.

(14) "Below the Line" costs include DDT&E system engineering, logistics, liaison engineering and management direct costs (like data deliverables.)

(15) All estimates exclude contractor fee and government program support factors.

The groundrules were applied consistently across the spectrum of hardware designs, with the exception of hardware quantities for phase C/D testing.

Mission Model Groundrules - The mission model shown in figure 22.1 is used for the Modification 6 cost analysis activity. The mission model establishes the total number of production vehicles required for accomplishment of the projected customer needs. It also is used to estimate the quantities of expendable hardware kits required for those

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Personnel Size:	10	4	10		(TEST FLTS)
Flight Mission:	Station	Servicing	Lunar/Mars	Total	
1999 START GROUND TESTS					
2000 FACILITIES SETUP					
2001 QUAL./PATHFINDER					
2001 UMANNED FLT TEST				0	(2) Unmanned
2002	1	1	0	2 +	(2) Manned
2003	2	2	0	4	
2004	3	2	0	5	
2005	4	3	2	9	
2006	5	3	2	10	
2007	5	3	2	10	
2008	6	6	2	14	
2009	6	6	2	14	
2010	6	6	2	14	
2011	6	6	2	14	
2012	6	6	2	14	
2013-2021	(SAME RATES PER YEAR AS 2012)			126	(14/Yr.)
2022	6	6	2	14	
Total	110	104	36	250 +	(4) First Times
Average	4.4	4.2	1.4	10	

Figure 22.1. Mission Model Groundrules

PLS vehicles which use expendable flight hardware to accomplish the mission. The current mission model includes satellite servicing missions (small repair, EVA/IVA inspection, RCS refueling, etc.) for a total of 250 flights plus four (4) Design, Test and Evaluation (DT&E) development flights to certify the system for operational use by the U.S. Government. Mission life of the vehicles was set at 50 flights per vehicle before major overhaul, with a design life of 100 flights per vehicle.

22.2 Test Hardware Quantity Matrices

The previous biconic configuration test hardware quantities were reviewed from the PLS study contract beginning cost analysis. Figure 22.2-1 is a copy of the biconic test hardware matrix from the October, 1990 final review. This information was carried forward to the new cost evaluation process and added to new estimated test hardware requirements for the low L/D, lifting body, and winged candidate PLS configurations.

Figure 22.2-2 contains the DDT&E test quantities assumed for each configuration. The plus (+) after quantities in the matrix indicates partial units for ground testing. The three tenths of a unit for avionics and structures on the winged vehicle design is for increased control surfaces equipment. The most noticeable change in quantities is the auxiliary equipment parachute quantities variance due to the differences in landing modes between the configurations.

22.3 DDT&E Comparison of PLS Candidates

Design, Development, Test, and Evaluation (DDT&E) cost estimates were produced with the Boeing Parametric Cost Model (PCM) (in constant-year, 1991 dollars, for each Boeing PLS candidate configuration. Figure 22.3-1 contains a summary of the preliminary planning estimates for the four candidate conceptual designs. Engineering design did not vary more than 10 percent between the different designs. The most significant differences in cost estimates are in hardware fabrication and tooling, due to increasing part count, increased manufacturing complexity of control surfaces, and some equipment reusability.

The least expensive was the low L/D system, but it is also the least flexible for abort options and quick turnaround. The most reusable was the winged vehicle, but it also has the highest cost estimate for development. The reusability complexity is reflected more in the "below the line" costs. The winged vehicle has a higher estimated logistics non-recurring cost, but much lower recurring production costs due to the

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Test Requirement	Structures	LES	OMS Eng.	Avionics	LSS	Chutes
	Quantity of Hardware Planned					
Static & Thermal	1 (incl.TPS)	-	1 Eng.	-	-	2 sets
Dynamic & Failsafe	1	-	-	-	-	6 sets
Mockups & Trng.	0.3 (use static)	1	3 Eng.	1	0. 5	-
Recovery Simul.'s	0.5	-	-	1	-	25 sets
LES Simulator	0.5 (mass sim.)	5	-	1	-	10 sets
Qual./Pathfinder	Proto #1 ----------					Proto #1
Avionic/LSS labs	-	-	-	1	1	-
"Iron Bird" & SIL	0.1 (equip.)	Ctrl. & Valves	Fld. Sply. Controller	1	0.3	0.5
S/W Dev. Facility	0.1 (equip.)			1	0.2	0.5
Propulsion Tests	0.5	4 Eng.	9 Eng.	-	-	-
Protoflight Vehicles	2 (incl. TPS)	2	6 Eng.	2	2	4 sets
Totals (equiv. units) - (subsystems)	6.0 Struc. 5.0 TPS	12.0 Eng. 13.0 Equip.	19.0 Eng.	8.0	5.0	47.0 Chutes 9.0 Equip.

Figure 22.2-1. Biconic Test Hardware Matrix

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(Average Quantity of Equivalent Sets in FSD)

Hardware Subsystem	Low L/D	Biconic	Lifting Body	Winged
Structures	6	6	6	6.5
Launch Escape Equip.	11+	11+	7+	7+
LES Engine	12	12	12	12
OMS Adapter	8	8	7	7
OMS Engines	19	19	19	19
Avionics	8	8	8	8.3
Power Supply	4+	4+	4+	4+
Life Support	5+	5+	5+	5+
AuxiliaryEquip. & Parachutes	9 47/141	9 47	6 10	6 10

Figure 22.2-2. Test Quantity Matrix Comparison

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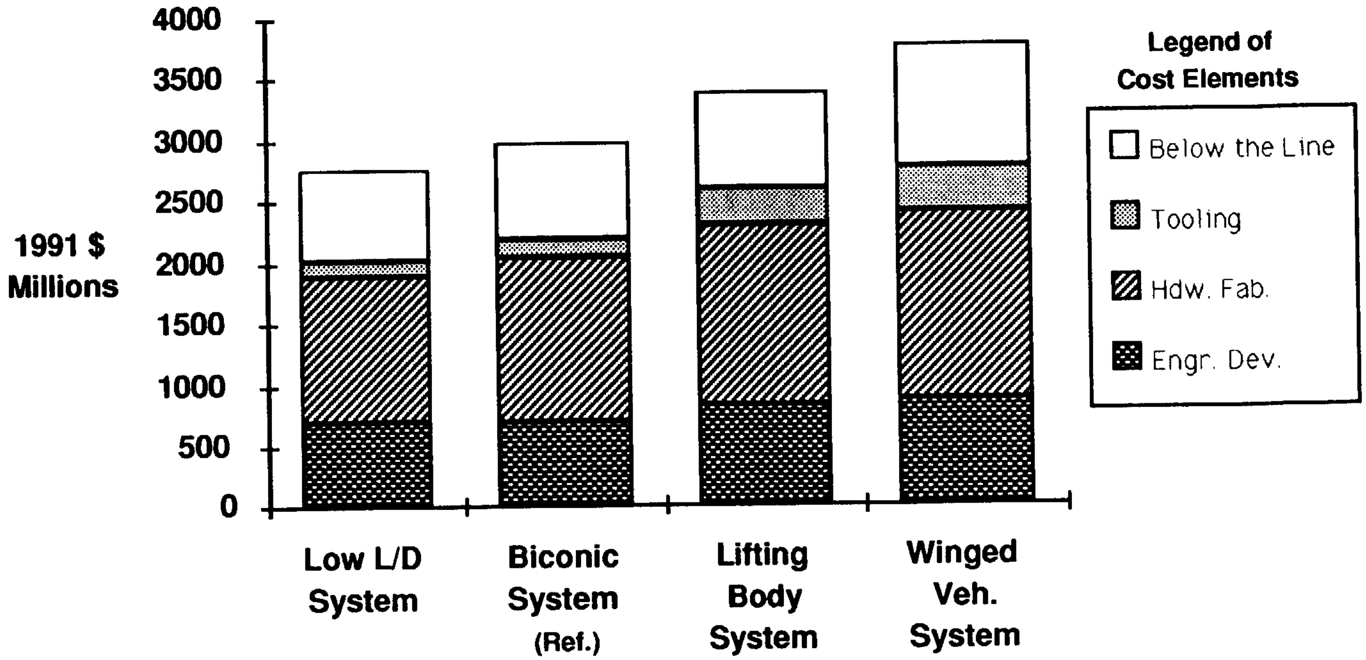
PLS DDT&E Estimates Less Fee & Gov. Factors



PLS Candidate Configurations

DDT&E Comparison Summary -1991 Dollars in Millions

	Engr. Dev.	Hdw. Fab.	Tooling	Below The Line	Total
Low L/D System	688	1,210	115	746	$ 2,759
Biconic System	693	1,345	141	791	$ 2,970
Lifting Body System	809	1,482	274	828	$ 3,393
Winged Veh. System	871	1,537	362	990	$ 3,760

Figure 22.3-1. Relative DDT&E Cost Estimates

requirement for fabrication of a minimum number of Orbital Maneuvering System (OMS) propulsion and tank hardware sets.

Figures 22.3-2 through 22.3-5 contain the output cost estimate summaries, by PLS conceptual design, from the Boeing PCM estimating system. The manufacturing (MFG) column is the estimate for the fabrication of the test hardware quantities shown in the figure 22.2-2 matrix shown in the previous section.

22.4 Facilities Estimates Comparison

A comparison of facilities costs was chosen for the analysis based on the conceptual designs. Because the lifting body design and winged vehicle had very similar landing characteristics (they both use an aircraft runway,) the facilities estimate was considered very similar. (The initial estimates were so close that they were not considered within the accuracy of the preliminary planning estimates.) Therefore, a top-level comparison was struck between the parachute and parafoil vehicles versus the higher L/D ratio vehicles.

Figure 22.4 shows the results of the top-level launch and mission support facilities cost assessment. The preliminary analysis indicates a difference of only 4 percent between the two estimates. The minor differences are in recovery equipment, landing site preparation, carrier aircraft support equipment (abort recovery), and processing and refurbishment. No definable differences are envisioned for the training facility, since most of its complexity is driven by docking and servicing training in a similar control cab environment. Further study is required to establish more variance or the lack of variance between the facilities costs for the four candidate Boeing PLS configurations.

22.5 Preliminary Production Estimates

PLS production unit cost estimates are based on the concept definition descriptions and the figure 22.5-1 groundrules. The groundrules include some assumptions on fiscal year lot buy authorization planning and an advanced procurement (long lead) start year of FY 1999 for the first lot. Quantities were not varied because the vehicles were not adjusted for different design life.

Figure 22.5-2 compares the four vehicle theoretical first unit (TFU) costs in relative dollars, less contractor fee and government program support factors.

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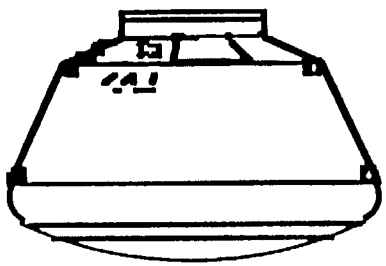
1991 $ IN MILLIONS
BALLISTIC CONFIGURATION



TITLE	ENGR	MFG	TOTAL
HARDWARE	688.3	974.3	1662.6
FINAL ASSEMBLY & C/O		138.4	138.4
SPARES		97.4	97.4
HARDWARE TOTALS	688.3	1210.2	1898.5
BELOW THE LINE COST:			
SYSTEM ENG & INTEG	77.8	0.0	77.8
SYSTEM TEST	264.4		264.4
PECULIAR SUPT EQUIP	77.7	62.4	140.1
TOOLING		114.7	114.7
OTHER	146.5	117.5	264.0
BELOW THE LINE TOTAL	566.4	294.6	861.0
TOTAL ESTIMATE	1254.7	1504.8	2759.5

*** Note: All estimates EXCLUDE contractor fee, government support, and requirements change factors.**

Figure 22.3-2. Low L/D DDT&E Estimate

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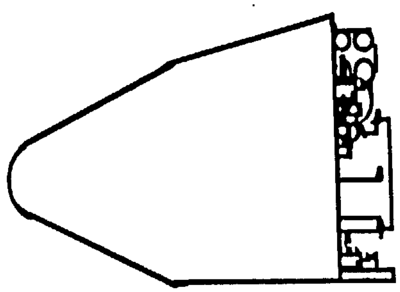
1991 $ IN MILLIONS
BICONIC CONFIGURATION



TITLE	ENGR	MFG	TOTAL
HARDWARE	692.8	1081.7	1774.5
FINAL ASSEMBLY & C/O		155.2	155.2
SPARES		108.2	108.2
HARDWARE TOTALS	692.8	1345.1	2037.9
BELOW THE LINE COST:			
SYSTEM ENG & INTEG	82.0	0.0	82.0
SYSTEM TEST	271.0		271.0
PECULIAR SUPT EQUIP	84.8	69.9	
TOOLING		140.7	140.7
OTHER	148.5	135.3	283.8
BELOW THE LINE TOTAL	586.3	345.9	932.2
TOTAL ESTIMATE	1279.1	1691.0	2970.1

* Note: All estimates EXCLUDE contractor fee, government support, and requirements change factors.

Figure 22.3-3. Biconic DDT&E Estimate (Ref.)

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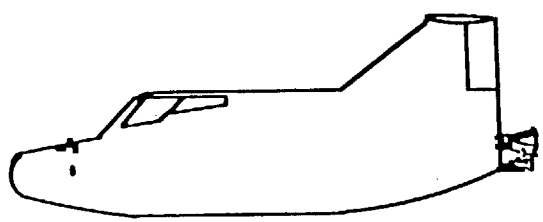
1991 $ IN MILLIONS
L. BODY CONFIGURATION



TITLE	ENGR	MFG	TOTAL
HARDWARE	809.0	1194.8	2003.8
FINAL ASSEMBLY & C/O		167.4	167.4
SPARES		119.5	119.5
HARDWARE TOTALS	809.0	1481.6	2290.6
BELOW THE LINE COST:			
SYSTEM ENG & INTEG	84.2	0.0	84.2
SYSTEM TEST	296.6		296.6
PECULIAR SUPT EQUIP	84.6	75.4	
TOOLING		274.3	274.3
OTHER	151.0	136.2	287.2
BELOW THE LINE TOTAL	616.4	485.9	1102.3
TOTAL ESTIMATE	1425.4	1967.5	3392.9

BOEING

* **Note: All estimates EXCLUDE contractor fee, government support, and requirements change factors.**

Figure 22.3-4. Lifting Body DDT&E Estimate

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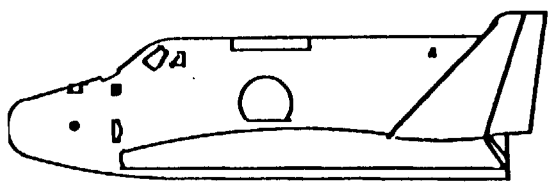
1991 $ IN MILLIONS
WINGED CONFIGURATION



TITLE	ENGR	MFG	TOTAL
HARDWARE	871.5	1235.6	2107.1
FINAL ASSEMBLY & C/O		177.5	177.5
SPARES		123.6	123.6
HARDWARE TOTALS	871.5	1536.7	2408.2
BELOW THE LINE COST:			
SYSTEM ENG & INTEG	103.6	0.0	103.6
SYSTEM TEST	339.1		339.1
PECULIAR SUPT EQUIP	114.2	80.0	
TOOLING		362.4	362.4
OTHER	196.6	155.8	352.4
BELOW THE LINE TOTAL	753.5	598.2	1351.7
TOTAL ESTIMATE	1624.8	2134.8	3759.6

BOEING

* Note: All estimates EXCLUDE contractor fee, government support, and requirements change factors.

Figure 22.3-5. Winged Vehicle DDT&E Estimate

Task 3 - Cost Estimation Final Review (91$M)

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PLS Facility	Location	Low L/D & Biconic	Lifting/Winged
Vehicle Processing	KSC	$ 39.6 M	$ 42.4 M
Refurbishment Wing	KSC	22.0	23.0
Fuel Deservicing Area	KSC	2.8	2.8
Engine Test Facilities	LeRC MSFC	(GFS)	(GFS)
ALS Launch Processing	ETR *	(GFS)	(GFS +TBD GSE)
C-5/CAM Loading Equip.	Portable	1.7	5.0
Landing Site	ETR	6.6 (zone)	11.0 (taxiway & CSE)
Mission Control Center	JSC	35.3	35.3
PLS Training Center	JSC	250.0	250.0
Recovery/Other Equip.	ETR	55.0	58.5 (Ship Mod's & Tailcone)
Total Estimate -		$ 413.0 M	$ 428.0 M

* Note: Assumes ALS docks, roads, recovery ship, and cargo processing facility (adapter processing) are in place.

Figure 22.4. Facilities Estimates Comparison

Program Cost Estimation Review

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Production Quantities By Fiscal Year Buy:

- 250 missions for PLS requires 11 PLS flight vehicles.
- The actual mission will need only nine (9) operational units, as an allowance for unplanned operations events.
- Two (2) operational spare vehicles: one for operational availability (e.g. - for vehicle loss or emergency rescue mission); and one for a scheduled maintenance spare.

Fiscal Year Lot Buy Plan (includes satellite sevicing):

Fiscal Year	Lot Buy No.	Vehicle Number	Delivery Year
FY 1999	Long Lead #1	Prod. #1 Parts	FY '99-2000
FY 2001	Lot Buy #1	Prod. #1	FY 2002 (Dec.)
		Prod. #2	FY 2003
		Proto Mod. (#3)	FY 2004
FY 2003	Lot Buy #2	#4 thru #7 Units	FY '05-2006
FY 2005	Lot Buy #3	#8 thru #11 Units	FY '07-2008

Figure 22.5-1. Production Lot Buy Groundrules

Program Cost Estimation Review

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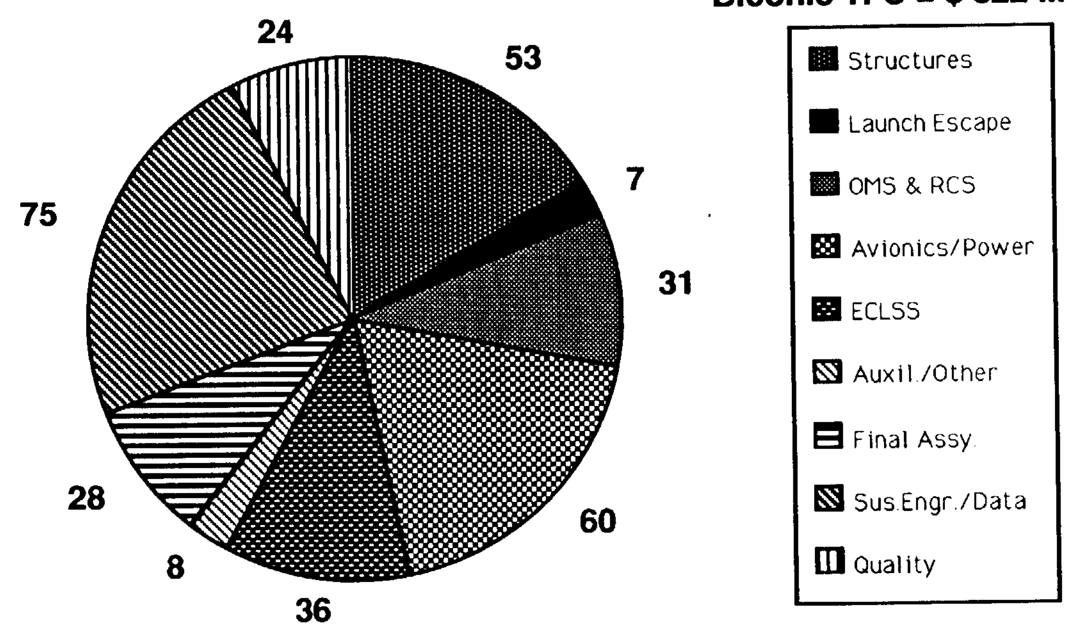
Reference Vehicle (Biconic) TFU Cost Breakout
(1991$ Millions)

Biconic TFU = $ 322 M



COMPARISON OF FIRST UNIT PRODUCTION ESTIMATES*

Low L/D	Biconic	Lifting Body	Winged
$304 M	$322 M	$368 M	$421 M

* Note: All estimates EXCLUDE contractor fee, government support, and requirements change factors.

Figure 22.5-2. Theoretical First Unit Costs

The biconic configuration cost breakout in the form of a pie chart is also presented in figure 22.5-2. The largest vehicle unit cost contributors are recurring production engineering and data support (liaison design support engineering, system engineering, production engineering, logistics , and acceptance test combined), avionics subsystems, structures and mechanisms (excludes tankage), environmental control and life support subsystem (ECLSS), and the orbital maneuvering system (or "OMS"; includes tankage) and reaction control subsystem (RCS).

Even though the winged vehicle TFU is substantially higher in estimated cost, the summary of total production relative dollar costs shown in figure 22.5-3 indicates a different conclusion. The Boeing lifting body and winged vehicles have less expendable hardware in their conceptual designs. Production (operational) quantities being held as equal, the lifting body and winged vehicles are less expensive to produce due to reuse of expensive components in the system. The vehicle modification costs and support equipment cost differences in the Boeing cost estimates were lower than the overall system estimate accuracy level of the Boeing cost model.

Further reliability and design life analyses of the four configurations may change the production estimates and the conclusions drawn from the revised comparison.

22.6 Preliminary Operations Estimate Comparison

Figure 22.6-1 contains an update to the biconic reference vehicle operation and support (O&S) cost estimate. The update includes schedule slide impacts after the last Boeing PLS presentation in October of 1990. The biconic estimate shown is the reference estimate.

The initial analyses of the low L/D and biconic systems yielded very little difference between cost estimates. The winged versus lifting body initial analysis also indicated very little difference between those two O&S cost estimates. Therefore, a summary comparison in relative dollars was drawn between the biconic and winged vehicles. Further operations definition studies and reliability analysis of the four PLS vehicle designs may reveal more distinctions in cost between the two pairs of estimates.

Figure 22.6-2 is a preliminary cost comparison summary of the winged configuration versus the biconic configuration. The winged configuration is slightly more expensive

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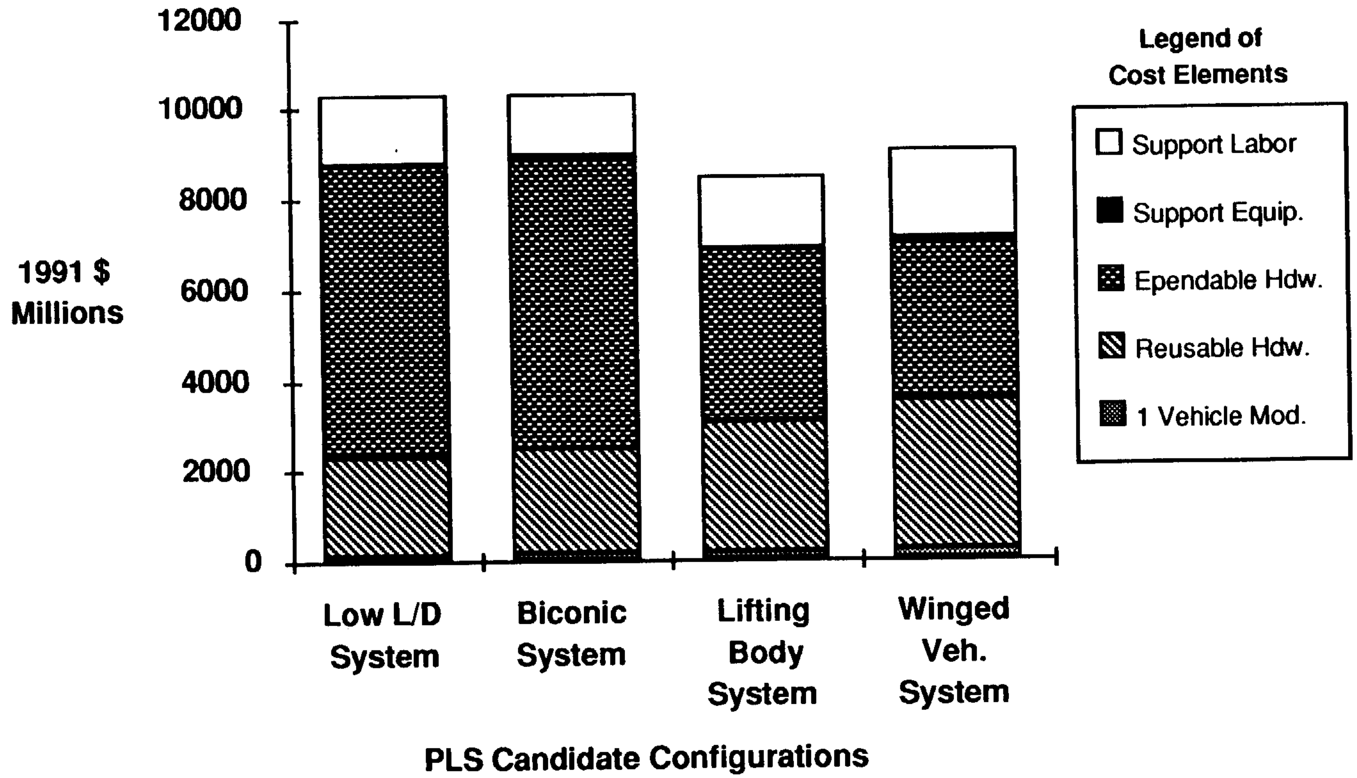
PLS Production Estimates Less Fee & Gov. Factors



10 reusable units + 1 Mod. & 250 sets of expendable hdw.

Figure 22.5-3. Relative Production Costs (91$M)

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(Updated to include * revised "Other Op.s" labor factor, 2 yr. schedule slide, and 1991 rates)

Year	DT & E Flights	Mission Flights	Contractor Support Manpower (Heads) Ground Ops	Mission/Launch Ops	* Other Ops.	Heads per Year	(91 $ M) Operations Labor Dollars
2001	2		200	135	150	485	$ 57.3 M
2002	2	2	254	135	150	539	60.4
2003		4	254	135	150	539	60.4
2004		5	308	200	173	681	79.4
2005		9	525	200	273	998	104.7
2006		10	579	200	273	1052	108.9
2007		10	579	200	273	1052	108.9
2008		14	795	200	273	1268	125.8
2009		14	795	200	273	1268	125.8
2010		14	795	200	273	1268	125.8
2011		14	795	200	273	1268	125.8
2012		14	795	200	273	1268	125.8
2013		14	795	200	273	1268	125.8
2014		14	795	200	273	1268	125.8
2015		14	795	200	273	1268	125.8
2016		14	795	200	273	1268	125.8
2017		14	795	200	273	1268	125.8
2018		14	795	200	273	1268	125.8
2019		14	795	200	273	1268	125.8
2020		14	795	200	273	1268	125.8
2021		14	795	200	273	1268	125.8
2022		14	795	200	273	1268	125.8
TOTALS	4	250	14,624	4,205	5,537	24,366	$ 2,467.0 M
	Flight Tests	Mission Sorties	Manyears (Ground Support)	Manyears (Mission/Launch)	Man years Others @ ETR	Total Man years	Labor (less O/T) Cost Estimate

Figure 22.6-1. O&S Manpower Example (Ref.)

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(1991 Dollars in Millions)

Operations- 22 Years @ 254 Flights: (includes 4 test flt.'s & LES/Delta cert. flt.'s)	(Config. 2A) Biconic	(Config. 4A) Winged
- Processing (at KSC)	$ 1,069.1 M	$ 1,122.6
- Integration	28.9	37.6
- Launch Operations	180.6	180.6
- Mission	541.9	541.9
- Landing/Recovery	46.1	23.0
- Non-Nominal Ops. (O/T @ 15%)	257.1	266.2
- Logistics	225.5	248.0
- Base operations (KSC,JSC)	374.9	374.9
Subtotal, O&S Labor Estimate -	$ 2,724.1 M	2,794.8
- Facilities Maintenance (4% yr.)	363.4	376.6
- Replenishment Spares (14 yrs.@ 9%)	1,479.3	1,899.8
Subtotal O&S (less consumables) -	$ 4,566.8	5,071.2
- ALS ($88 M/flt.) /Delta ETO Services	22,652.0	22,652.0
Total O&S Estimate -	$ 27,218.8 M	$ 27,723.2 M

* Note: All O&S estimates EXCLUDE government support, and requirements change factors.

Figure 22.6-2. Operation & Support Comparison

due to more maintenance and refurbishment tasks involved with the reusable hardware (but not enough to negate the greater implied savings in production costs with the current selected Boeing conceptual designs.) The variance in total (1.9%) is not considered with the accuracy of the preliminary O&S planning estimate (+ or - 25%.)

22.7 Cost per Flight Comparison

The biconic and winged vehicle preliminary design comparison of cost per flight for 250 operational flights (with development and production dollars amortized in) is presented in figure 22.7. The increased cost of development (DDT&E) and O&S for the winged vehicle is totally offset by the reusable hardware savings in production. The end cost per flight for both vehicles is the same in this preliminary evaluation. More in-depth analysis will be required to test this initial evaluation.

22.8 Cost Estimation Summary

The planning estimates in this report are based on Boeing preliminary designs of varying depth of knowledge and evaluation. The biconic vehicle has more Boeing design experience and detail in description than the other three vehicle design candidates. Further system evaluation would be required to evaluate the low L/D, lifting body, and winged configurations to the level of detail produced in the prior biconic shape technical, schedule, and cost analysis of the PLS system life cycle.

Figure 22.8 summarizes the results of the contract Modification 6 cost analysis. In addition to this summary cost estimation work, Boeing has provided NASA with detailed proprietary cost model input description sheets for each of the Boeing PLS conceptual design candidate configurations. These cost estimate input description sheets, and the resulting preliminary cost analysis results, will provide a well-documented PLS subsystem descriptions database for future PLS cost estimates accomplished by Boeing for the NASA program office.

Program Cost Estimation Review

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(Constant-Year 1991 Dollars in Millions)

NET cost per flight shows no difference with preliminary O&S analysis.

Life Cycle Cost Element	Biconic Ref. Vehicle Average Cost/Flight	Winged Vehicle Average Cost/Flight
Sunken Costs - DDT&E	$ 16.9 M	$ 21.7
Facilities Investment	1.6	1.7
Production Costs	58.6	51.6
Operations & Support	18.9	21.0
Booster (ALS) Cost/Flt.	88.0	88.0
Total Average Cost/Flight	$ 184.0 M	$ 184.0 M

Figure 22.7. Cost Per Flight Comparison

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Program Cost Estimation Review

- Operational reliability and software differences have not been included in the preliminary cost analysis.
- The development cost estimate for the Biconic candidate is more competitive after updating the subsystems inputs.
- Little difference can be seen in facilities costs.
- The larger costs of winged vehicle development are cancelled out by lower production costs (less expendable hdw.)
- There is no cost difference in life cycle cost per flight for the two representative vehicles selected.

Figure 22.8. PLS Cost Analysis Conclusions

23 SUMMARY

The objective of the additional studies performed was to generate data on the entire spectrum of PLS configurations. No attempt has been made to select a "best" solution; rather the study was intended to provide unbiased information to those addressing the larger questions related to the scope and purpose of future manned space transportation. There are, however, some significant conclusions that can be drawn from this study (presented here in no particular order of priority).

1 Any PLS shape can be built using 1992 technology.

2 The personnel. load for a PLS can be accommodated in configuration shapes that span the entire range of hypersonic L/D.

3 There is no singular operational concept that could be effectively applied to the entire range of configurations. Conversely, any particular shape will have a unique operational scenario associated with it.

4 No amount of aerodynamic performance (unpowered) capability can alleviate the problem of a water abort. There is always a portion of the ascent where a water landing is inevitable and proper design features should be included to ensure crew safety.

5 High lift shapes mounted atop an expendable launch vehicle can pose an appreciable problem. Solutions are possible, but will affect cost and schedule risk.

6 There are some outstanding philosophical questions that could dramatically alter conclusions concerning concept selection. For example: "what is the perceived 'value' of a runway landing?" or "is a 'pilot' necessary?". These questions are not directly answered by physical or cost analyses and historical comparisons are not necessarily valid in a world of changing technology.

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		B-175	A					B-211	A		

ACTIVE PAGE RECORD											
PAGE NO.	REV LTR	ADDED PAGES				PAGE NO.	REV LTR	ADDED PAGES			
		PAGE NO.	REV LTR	PAGE NO.	REV LTR			PAGE NO.	REV LTR	PAGE NO.	REV LTR
		B-212	A								
		B-213	A								
		B-214	A								
		B-215	A								
		B-216	A								
		B-217	A								
		B-218	A								
		B-219	A								
		B-220	A								
		B-221	A								
		B-222	A								
		B-223	A								
		B-224	A								
		B-225	A								
		B-226	A								
		B-227	A								
		B-228	A								

BOEING

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL
A	Added Appendix B "Additional Concept Evaluation"; Revised Table of Contents, List of Figures, List of Tables List of References, and Active Sheet Record accordingly.		Prepared by: 6/20/91 J. E. Helser Supervised by: C. W. Hosking Approved by: E. D. Wetzel Approved by: D. J. Rohrbaugh